New Advances in Aging

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SCIENCE FOR THE CURIOUS

Discover

October 2015

Breakthrough Research

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- Restoring heart muscle
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Chicago Doctor Invents *Affordable* Hearing Aid
Outperforms Many Higher Priced Hearing Aids

Reported by J. Page

CHICAGO: A local board-certified Ear, Nose, and Throat (ENT) physician, Dr. S. Cherukuri, has just shaken up the hearing aid industry with the invention of a medical-grade, affordable hearing aid. **This revolutionary hearing aid is designed to help millions of people with hearing loss who cannot afford—or do not wish to pay—the much higher cost of traditional hearing aids.**

"Perhaps the best quality-to-price ratio in the hearing aid industry" — **Dr. Babu, M.D.**
Board-Certified ENT Physician

Dr. Cherukuri knew that untreated hearing loss could lead to depression, social isolation, anxiety, and symptoms consistent with Alzheimer's dementia. **He could not understand why the cost for hearing aids was so high when the prices on so many consumer electronics like TVs, DVD players, cell phones, and digital cameras had fallen.**

Since Medicare and most private insurance do not cover the costs of hearing aids, which traditionally run between $2,000-$6,000 for a pair, many of the doctor's patients could not afford the expense. Dr. Cherukuri's goal was to find a reasonable solution that would help with the most common types of hearing loss at an affordable price, not unlike the **"one-size-fits-most" reading glasses** available at drug stores.

He evaluated numerous hearing devices and sound amplifiers, including those seen on television. Without fail, almost all of these were found to amplify bass/low frequencies (below 1000 Hz) and not useful in amplifying the frequencies related to the human voice.

Inspiration From a Surprising Source

The doctor's inspiration to defeat the powers-that-be that kept inexpensive hearing aids out of the hands of the public actually came from a new cell phone he had just purchased. **"I felt that if someone could devise an affordable device like an iPhone® for about $200 that could do all sorts of things, I could create a hearing aid at a similar price."**

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Affordable Hearing Aid With Superb Performance

The high cost of hearing aids is a result of layers of middlemen and expensive unnecessary features. Dr. Cherukuri concluded that it would be possible to develop a medical-grade hearing aid without sacrificing the quality of components. The result is the **MD**HearingAid ***PRO***, well under $200 each when buying a pair. **It has been declared to be the best low-cost hearing aid that amplifies the range of sounds associated with the human voice without overly amplifying background noise.**

Tested By Leading Doctors and Audiologists

The **MD**HearingAid ***PRO*** has been rigorously tested by leading ENT physicians and audiologists who have unanimously agreed that the **sound quality and output in many cases exceeds more expensive hearing aids.**

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"I have been wearing hearing aids for over 25 years and these are the best behind-the-ear aids I have tried. ***Their sound quality rivals that of my $3,000 custom pair of Phonak Xtra digital ITE."***
—Gerald Levy

"I have a $2,000 Resound Live hearing aid in my left ear and the **MD**HearingAid ***PRO*** *in the right ear.* ***I am not able to notice a significant difference in sound quality between the two hearing aids."*** —Dr. May, ENT Physician

"They work so great, my mother says she hasn't heard this well in years, even with her $2,000 digital! ***It was so great to see the joy on her face.*** *She is 90 years young again."*
—Al Peterson

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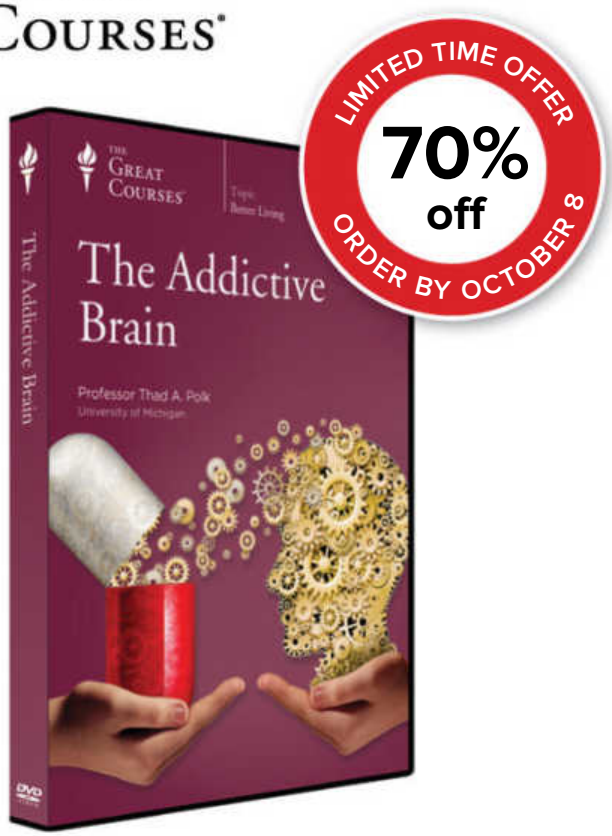

What Happens in the Addictive Brain?

Addiction touches us all. Whether it's a friend who can't quit smoking, a colleague afflicted with alcoholism, or a relative abusing prescription drugs, we all know someone who suffers from some form of addiction—we may even have an addiction ourselves. But what actually happens to the brain on drugs, and why do addicts behave the way they do? What can neuroscience tell us about addiction?

The Addictive Brain explains what happens at a neural level when someone sips coffee, smokes a cigarette, snorts cocaine, and more. Taught by Professor Thad A. Polk of the University of Michigan, these twelve eye-opening lectures reveal what happens when drugs enter the brain and the way drug molecules induce pleasure and shut down the ability to make sound decisions. You also investigate addictive behaviors such as gambling, binge eating, and excessive video gaming—as well as potential treatment options. Insights into the underlying mechanisms of addiction can help motivate people to seek treatment, and can provide friends and loved ones with a deeper understanding.

Offer expires 10/08/15

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2. The Psychology and Neuroscience of Reward
3. How Addiction Hijacks the Brain
4. Genetics—Born to Be an Addict?
5. Your Brain on Drugs
6. Why We Crave Coffee and Cigarettes
7. Alcohol—Social Lubricant or Drug of Abuse?
8. The Science of Marijuana
9. Stimulants—From Cocaine to Ritalin
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OCTOBER 2015
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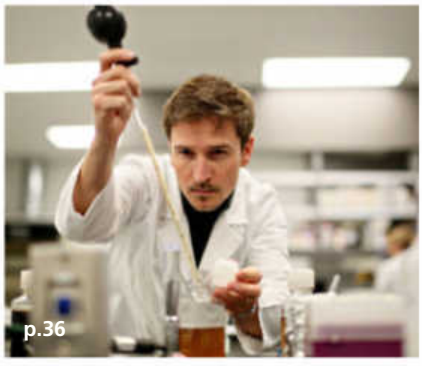
The Compact Muon Solenoid particle detector at the Large Hadron Collider (LHC). The LHC is the biggest and most powerful particle collider — for now.

ON THE COVER *Photo by mevansliStock*

FEATURES

COVER STORY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COLUMNS & DEPARTMENTS

OPPOSITE: CERN; THIS PAGE FROM TOP: SANDY HUFFAKER; STUART BRIERS

Editor's Note

No Old News

A look at the research behind healthy-aging tips and advice.

I spent several years as a health and medical writer, and published lots of advice columns in my time. You know the kind: packed with tips for losing weight, getting in shape, picking the right foods and so on, ad nauseam.

Between you and me, those stories weren't my favorite assignments. Plenty of readers found them lacking, too. They'd write in asking for more information. They didn't want just distilled tips and plans. They were curious about the research *behind* the advice — how and why scientists came to conclusions that they did. And they didn't want old news or advice based on research that was sometimes conducted years ago. They wanted to know what was in the works. What was coming next.

Well, *what's next* is at the core of the cover story (page 25) of this issue. We'll also look at a few of the common healthy-aging strategies you've heard about. Finally, we did include a few lab-tested tips that just might help readers live better longer. What could it hurt to try them?

NEXT ISSUE: *Peer beneath the layers of the ancient city of Armageddon. Look to the heavens with "stellar archaeologists" seeking the origins of the first stars. This and much more in our November issue. See you then.*

Stephen C. George, **EDITOR IN CHIEF**

YOUR REPLY

Lots of readers are still writing in to answer the question I posed a few issues back: If you could visit the future, how far ahead would you go, and what would you hope to see? Darryl Suskin spoke for many when he wrote:

I wasn't alive during the broadcast of the moon landings. I just want to make sure I'm alive to see the broadcast of the first Martian landing.

But he added:

… and I'd like to visit far enough into the future where I get my flying car.

Right there with you, Darryl!

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THE CRUX

The Latest Science News & Notes

CERULEAN WAVES OF GLASS

For centuries, the Alpes-de-Haute-Provence region of southern France has been famous for its olive groves and vineyards. The agreeable climate has drawn a newcomer with a different kind of thirst: Les Mées PV Park, where nearly 113,000 solar modules imbibe the plentiful sunshine. The modules, spread out over about 500 acres, are built without concrete foundations and follow the rolling terrain. When the solar modules reach the end of their 20-year life cycle, the land can be restored to agricultural use, according to a spokesman for Enfinity, which manages the photovoltaic farm. — ERNIE MASTROIANNI; PHOTO BY JEAN-PAUL PELISSIER/REUTERS

Do You Know the Way to Space?

Only one question matters: What's your net worth?

Billions and billions.

Are you OK with leaving behind everything you've ever known and loved?

Could you stare for days out the window at a boring gray surface?

I could if I'm in space!

I can't stare at anything for days.

Sure! I'm the best part of my life anyway.

No, I'd miss my adoring fans.

Would you like to hang out with Virgin CEO Richard Branson?

Richard who? No thanks.

Bring on The Branson.

Mere millions.

Four to five zeros.

How do you feel about retiring someday?

Rest is for the weak.

It'd be nice.

I saved money by skipping lattés this month.

Do you have the right stuff to join NASA?

Roger!

Not in real life.

Need to clear your head? Perhaps a flight beyond Earth's atmosphere is the ticket. But with the growing number of options over the next several years, it can be easy to feel overwhelmed. Our flow chart will help steer you to the space trip that best fits your lifestyle and bank account. Regardless of the route, you'll be seeing stars before you know it.

— SARAH SCOLES

How long can you be in the same room with people before getting violent?

I envy sardines.

The length of a sitcom.

You should give them some of your money so they can go to space.

What kind of takeoff do you want?

A vertical takeoff in a single rocket.

Gradual jetlike ascent for a smoother, but longer, ride.

Can you handle a corkscrew descent, in which you spin all the way down?

Bring it.

Vomit.

Become an astronaut and make the space tourists (and everyone else) jealous.

Stay on this planet and take a nice Caribbean cruise instead.

Space Adventures

Launch date: 2018
Destination: Far side of the moon
Cost: $150 million
Pro: Being like legendary Apollo astronauts and getting closer to the moon than 99 percent of humanity!
Con: Thinking you should have gone to Mars.

Space Adventures

Launch date: Now
Destination: International Space Station
Cost: $52 million
Pro: Making friends with career astronauts!
Con: Boldly going where many have already gone.

Virgin Galactic

Launch date: 2016
Destination: Suborbital
Cost: $250,000
Pro: Riding in style with custom-fitted spacesuits and personalized seats. This is the brand-name spaceflight experience.
Con: Knowing that (like on any suborbital flight) your weightless view of Earth from above will last only a few minutes.

Space Adventures

Next launch date: TBD
Destination: Suborbital
Cost: $102,000
Pro: Making friends sit through the (free!) DVD you'll receive of your personal space experience.
Con: Feeling a gender barrier. Only one woman — 13 percent of all passengers — has flown on Space Adventures' previous orbital flights.

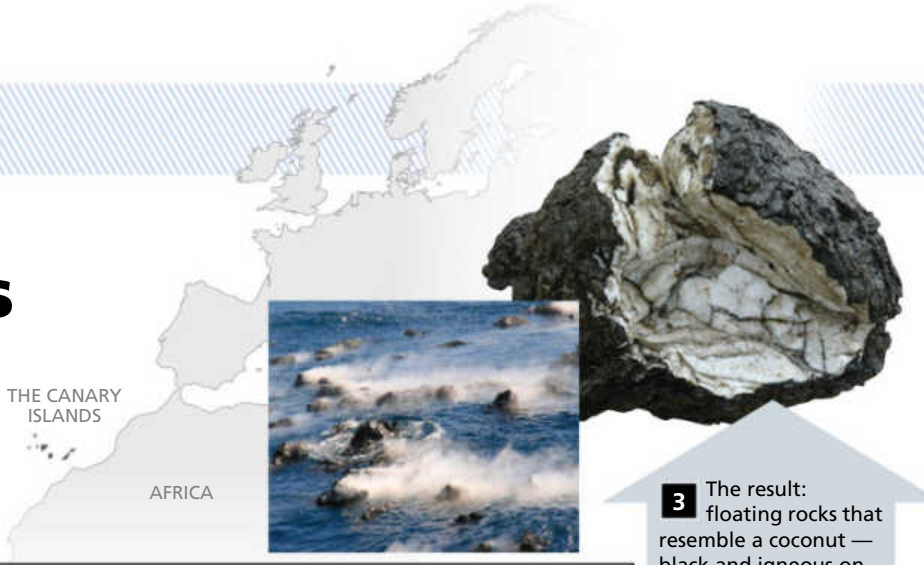
XCOR

Launch date: 2016
Destination: Suborbital
Cost: Starts at $95,000
Pro: Having a one-on-one experience with a pilot.
Con: Everyone knows you got the budget space trip.

CLOCKWISE FROM BOTTOM LEFT: NASA; ANTON BALAZH/SHUTTERSTOCK; MARK GREENBERG/VIRGIN GALACTIC; SPACE ADVENTURES; NASA; VIRGIN GALACTIC; SPACE ADVENTURES; XCOR AEROSPACE; MOON AND BACKGROUND STARS: ERNIE MASTROIANNI/DISCOVER

Rock of Ages

Tiny fossils survive a volcanic eruption and reveal the origins of an island chain.



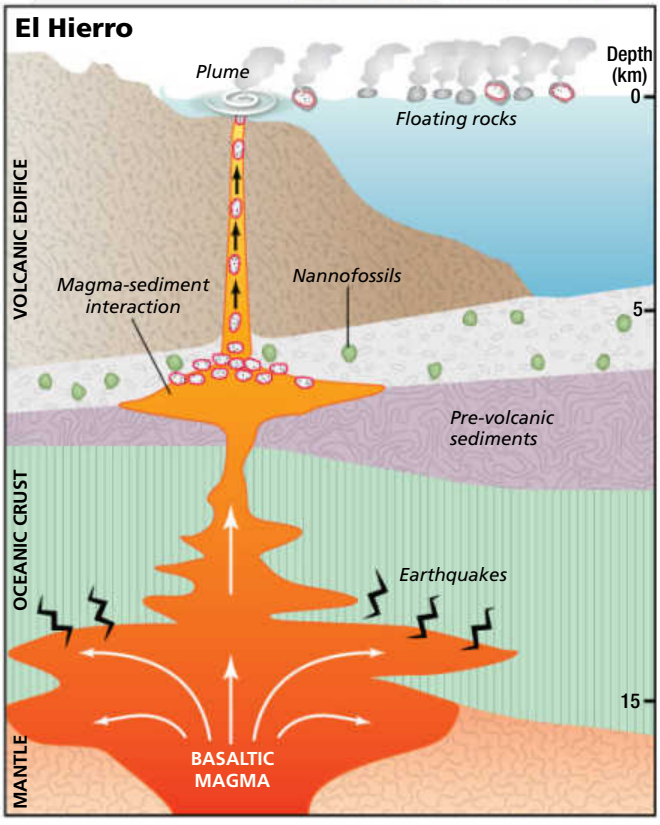
The Canary Islands, an autonomous community of Spain west of Morocco, spreads more than 300 miles across the Atlantic in an archipelago akin to Hawaii. Like the Aloha State, the Canaries were born from volcanoes — but researchers had debated exactly how.

When magma erupted from a crack in the ocean floor off El Hierro, the youngest, westernmost island, local volcanologist Vicente Soler headed out to sea, looking for answers. He found strange black rocks, some as large as soccer balls, floating in the bubbling, sulfurous seawater. He scooped them up with a fishing net.

It's rare, but not unprecedented, for frothy magma to harden into rock so light it floats. But trapped inside the floating rocks was something even more unusual: quartz minerals and banding patterns found in sedimentary rock, which magma typically melts.

The banded sediments contained tiny fossils of single-celled creatures, says Uppsala University volcanologist Valentin Troll, part of the team that published its findings in January in *Scientific Reports*. Those fossils helped solve a question that's dogged geologists for decades: How did the Canary Islands arise from the ocean depths?

The rocks' sedimentary interior contained fossils of single-celled algae called coccolithophores (circled in red, right). Researchers dated the fossils based on different patterns of tiny plates that each species had evolved. Based on the youngest coccolithophore present, it was determined that volcanic activity formed El Hierro in the last 2.5 million years. By contrast, the easternmost island has sediment that's 20 million years old. Since the island "birth order" moves from east to west, the Canaries must have formed as the continental plate drifted eastward over a stationary, periodically erupting plume of hot magma deep in Earth's mantle. — DAN FERBER



3 The result: floating rocks that resemble a coconut — black and igneous on the outside, white and sedimentary on the inside, with enough trapped air bubbles to make them lighter than Styrofoam.

2 The magma moved up to a layer of sedimentary rock more than a mile thick and 4 miles below sea level. There, the magma broke off chunks of the rock, melting most of the material. It continued rising and hit seawater quickly enough, however, to preserve about 10 percent of the sedimentary rock.

1 In the months before an October 2011 eruption, magma from the upper mantle accumulated in a layer of oceanic crust 6 to 10 miles below sea level.

FROM TOP: CARRACEDO ET AL. 2012, GEOLOGY TODAY 28, 53-58 (3); SCIENTIFIC REPORTS/NATURE PUBLISHING GROUP (ILLUSTRATION); NEONJA AND RICHARD BARTZ VIA WIKIMEDIA CREATIVE COMMONS (2)

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Seeing the Invisible

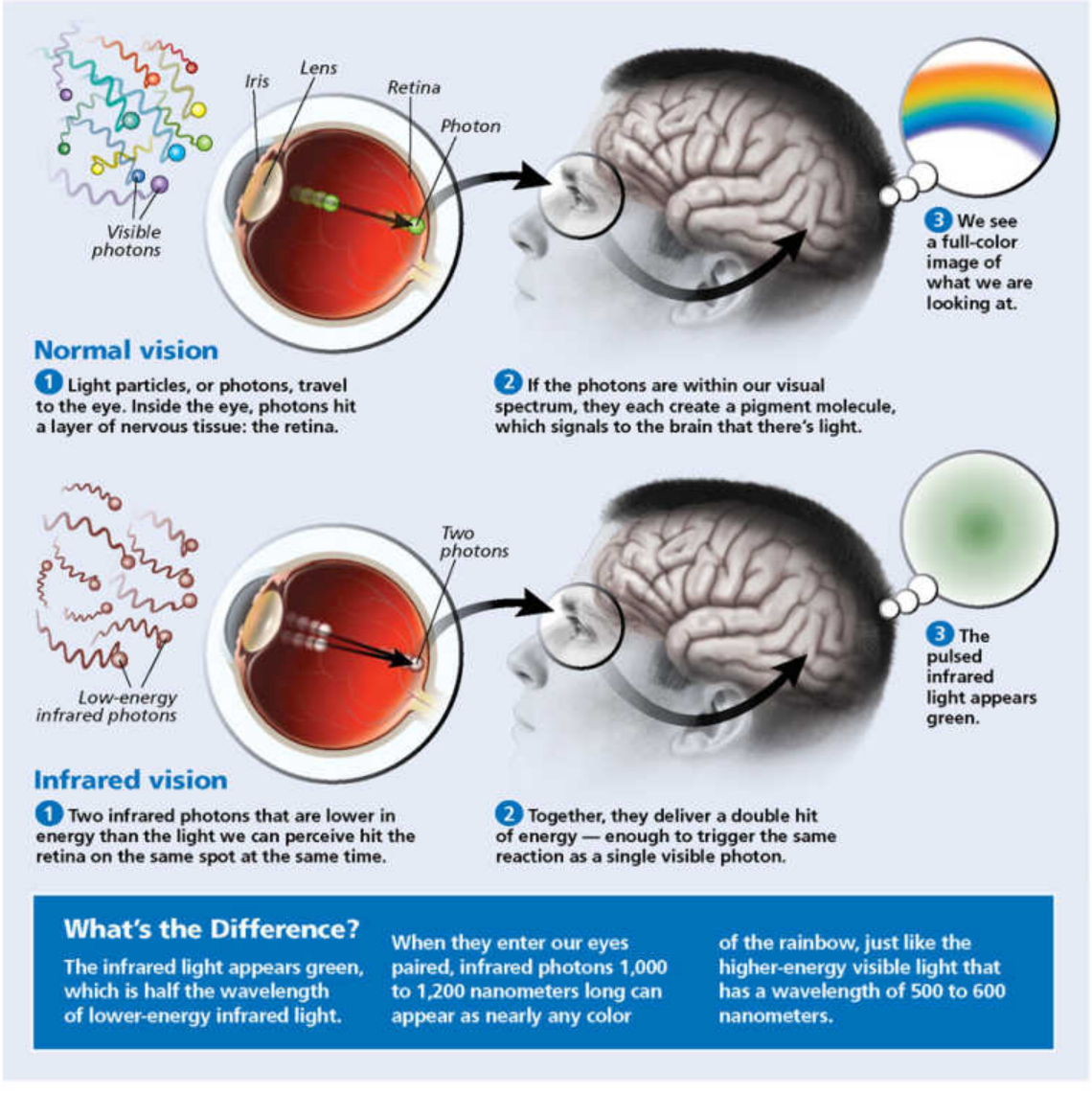
Scientists investigate the weirdness of infrared light — and how we perceive it.

While visiting a colleague's lab, eye scientist Grazyna Palczewska saw a pale green line of light coming from a machine. Odd, she thought, since the machine used low-energy infrared light, too faint to be visible to humans.

But over the past several decades, a handful of scientists like Palczewska have reported similar instances of seemingly superhuman vision.

Palczewska and her colleagues at Polgenix Inc. set up an experiment to investigate the phenomena and found that everyone might have this strange ability. When observing a rapidly pulsing infrared laser, each of 30 participants reported seeing the light, too.

If you want to see the whole infrared world, you'll still need goggles. But the team's computer simulations and calculations reveal a mechanism naturally occurring in our eyes that allows us to glimpse the low-energy light without the aid of technology. —SHANNON PALUS



ROEN KELLY/DISCOVER

Ask Discover

Q Why do planets rotate? I have been told the effects of their spinning, but never why they spin in the first place.

— Carson Lee Fifer Jr. , Alexandria, Va.

A To answer this question, it helps to picture a game of pool. Hit the cue ball, and sometimes it strikes only a glancing blow on your target, setting it into a spin instead of launching it across the table. Most experts believe planets probably acquired their spin in much the same way, when clumps of matter collided during the planets' formation about 4.5 billion years ago.

But why do they spin in the same direction? When our solar system was nothing but a cloud of gas and dust, what was likely a shock wave from a nearby supernova bounced up against it and caused it to collapse. As it collapsed, its own gravitational forces pulled it into a flat, spinning disk. And since everything in our solar system was formed from that same disk, its momentum sent nearly everything spinning in the same direction. (Notable exceptions include Uranus and Venus, whose odd spins probably stem from subsequent collisions with asteroids.)

Our planets have continued spinning because of inertia. In the vacuum of space, spinning objects maintain their momentum and direction — their spin — because no external forces have been applied to stop them. And so, the world — and the rest of the planets in our solar system — keeps spinning. – KATIE BO WILLIAMS

Visit **DiscoverMagazine.com/Ask** for more answers. To submit a question, send an email to **Ask@DiscoverMagazine.com**

DID YOU KNOW?

The height of an average Dutchman has increased nearly 8 inches over the past 150 years. By comparison, the average American male's height grew only about 2.5 inches over that same period. Dutch people are now, on average, the tallest in the world; researchers credit all those inches to a number of factors, including heavy consumption of dairy products, universal health care and natural selection.

LEFT: IMAGINEERINX/SHUTTERSTOCK. RIGHT: SMILESTUDIO/SHUTTERSTOCK

Recipe for Success

Finding a better way to grow cells.

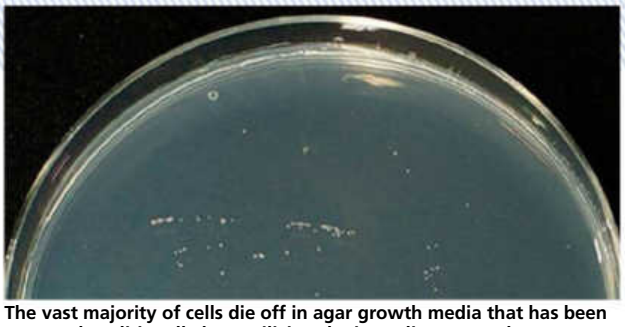
For years, a mystery known as "the great plate count anomaly" has plagued microbiologists: Counts of living cells grown on plates in the lab aren't as high as counts from the original sample, and no one knows why.

To grow these microorganism cultures in the lab, researchers house samples in petri dishes lined with a nourishing gel mixture derived from algae called agar growth media. But despite the nourishment, just 0.1 to 10 percent of cells make it.

It turns out the agar is the problem, says microbiologist Yoichi Kamagata at Hokkaido University in Japan.

The standard recipes require mixing agar and phosphate solution before sterilizing them via intense heat. But Kamagata and his team realized this sequence creates hydrogen peroxide, which destroys most of the cells. Sterilize the ingredients separately, and *voila*, a roughly tenfold increase in cell survival rates.

"I was thinking someone else would have done this kind of experiment, as we have 120 years of agar media history," Kamagata says. "Nonetheless, nobody cared about the media recipe." —LACY SCHLEY



The vast majority of cells die off in agar growth media that has been prepared traditionally by sterilizing the ingredients together.

Using the new method, agar prepared with individually sterilized ingredients proves much more hospitable to the cells growing within.

Y. KAMAGATA ET AL./APPLIED ENVIRONMENTAL MICROBIOLOGY/2014 DEC; 80(24): 7659–7666/ AMERICAN SOCIETY FOR MICROBIOLOGY

Flute or Fluke?

Scientists disagree on who or what put the holes in a prehistoric bone.

Experts disagree over whether this partial bone from an ancient bear leg, found in 1995, is a flute or just scraps from a hyena's meal.

Many experts believe an approximately 45,000-year-old bear femur could be a flute — the oldest known musical instrument. Ivan Turk discovered the bone in 1995 in Slovenia's Divje Babe Archaeological Park, among cave deposits containing Neanderthal tools. But is it a hominin-made flute, or just a bone scavenged by ancient hyenas? In Science Smackdown, we let experts argue both sides of the question.

A Bone Is Just a Bone

Turk and his followers are wrong, says Cajus Diedrich, a paleozoologist and cave researcher in the Czech Republic. They didn't properly consider the bone biting and crushing patterns of ice age hyenas that scavenged extensively in European cave bear dens.

In a recent *Royal Society Open Science* paper, Diedrich argues that a hyena could've bitten holes in the juvenile cave bear femur without crushing it because the young bone wasn't fully hardened and was still spongelike inside. The lack of counterbites on the other side actually makes sense, he says, because only the hyena's top teeth could puncture. So it's possible the now-extinct scavengers made the "flute."

Give Neanderthals Some Credit

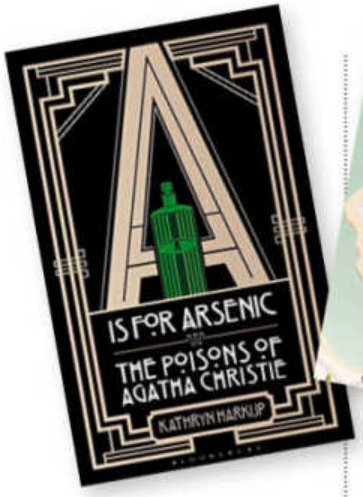
Jelle Atema, a Boston University biologist who created a replica of the femur from a cave bear fossil, isn't convinced. An accomplished flautist, Atema has followed the debate for decades. He believes Turk's initial excavation and subsequent experiments using hyenalike jaws on modern bear bones show the bone would've split and had counterbite marks. Using bone-cracking tests, "you can occasionally get a single hole, but not a row of nice, round holes all in one bone," Atema says.

Regardless of who or what made the holes, Atema says, people have played replicas to demonstrate that the holes produce different pitches. "One cannot dismiss this intriguing bone as a flute," he says. "But we can never be sure it was used as such. We were not there."

— JENNIFER ABBASI

See a re-creation of the flute being played at **DiscoverMagazine.com/Flute**

LEFT: PORTIA SLOAN ROLLINGS. RIGHT: STR/REUTERS/CORBIS



A IS FOR ARSENIC

The Poisons of Agatha Christie

By Kathryn Harkup

When it came to offing her characters, iconic crime novelist Christie preferred poison. Chemist Harkup delves deep into the history and science behind more than a dozen lethal substances, introducing each through its appearance in Christie's writing. You don't have to be familiar with the likes of Miss Marple or Hercule Poirot, however, to enjoy Harkup's detailed, near-gleeful dip into what she calls Christie's "deadly dispensary."

PLACES OF THE HEART

The Psychogeography of Everyday Life

By Colin Ellard

Despite the title, neuroscientist Ellard is decidedly unromantic about deconstructing both natural and human-made environments into components that trigger specific cognitive responses. From Neolithic monuments that awe to "playground casinos" that empty wallets, Ellard argues that a scientific understanding of how our surroundings affect us must be the foundation on which we build the cities and homes of tomorrow.

Other Pages We're Turning

RISKY MEDICINE

Our Quest to Cure Fear and Uncertainty

By Robert Aronowitz

Americans have the most advanced (and expensive) health care — but not the best health. Science and sociology historian Aronowitz suggests that our market-driven, risk management-focused health care culture has led to excessive tests and overdiagnosis. The cure? Reforming how we think about health and how it's practiced.

THE FOOD LAB

Better Home Cooking Through Science

By J. Kenji Lopez-Alt

Whether you want to make a foolproof Hollandaise or stop fretting about how often to flip your burger, James Beard Award-nominated columnist Lopez-Alt serves up nearly a thousand pages of practical advice and information with a side of snark.

EUREKA

How Invention Happens

By Gavin Weightman

Before (and after) the light bulb moment, when an idea becomes an innovation, there's plenty of failure, doubt and competition. Historian Weightman covers the setbacks and the successes in five case studies, from the Wright brothers' flying machine to the ubiquitous barcode.

CHILLED

How Refrigeration Changed the World and Might Do So Again

By Tom Jackson

Jackson's chronicle of cool will give you new appreciation for the (relatively) recent and now indispensable invention. Without mastering the big chill, we'd still be looking for the Higgs boson, and National Ice Cream Day would be very sad, indeed.

BOG BODIES UNCOVERED

Solving Europe's Ancient Mystery

By Miranda Aldhouse-Green

Like an Iron Age *CSI* detective, archaeologist Aldhouse-Green investigates the grisly deaths of men, women and children discovered millennia later in the peat bogs of Northern Europe.

LIONS IN THE BALANCE

Man-Eaters, Manes, and Men With Guns

By Craig Packer

Researcher Packer returns more than a decade after his memoir, *Into Africa,* with a fast-paced, unsentimental sequel about the kings of the savannah and the politics of protecting them.

—GEMMA TARLACH

Biohazard Warning

The scientist who first described biological diversity makes the case for saving it.

For the past half-century, Thomas Lovejoy has studied "the shimmering variety of life on Earth" in the Amazon rainforest. The 74-year-old tropical biologist, who teaches at George Mason University, coined the term *biological diversity* in 1980 to refer to the millions of different species that comprise life on Earth, of which scientists have documented perhaps 10 percent. Unfortunately, countless organisms will vanish before we ever discover them, let alone investigate their potential benefits in fields like medicine, agriculture and genetics. But if we work now to restore ecosystems, Lovejoy argues, we can avoid the worst of these losses — and slow down climate change, too.

Thomas Lovejoy has spent decades studying ecology and biodiversity, including several years examining the fragmentation of the rainforest in Manaus in the Brazilian Amazon, where he recently returned (above).

Q *Scientists say we face the largest mass extinction since the disappearance of the dinosaurs. You have pointed out that it isn't just species that are going extinct — it's entire ecosystems. Which ones are most threatened?*

A Most of the lowland tropical rainforests in Southeast Asia are already gone. Africa is now up for massive deforestation. We're seeing huge die-offs in the coniferous forests in western North America, due to the parasitic pine bark beetle. Native grasslands everywhere are being replaced by farms and pastures. The list goes on.

Q *What's causing these declines?*

A Habitat destruction is probably the leading cause. Wild places are vanishing fast. A close second is the spread of invasive species. There is also pollution — the soup of toxic chemicals we live in, the fact that we have distorted the nitrogen cycle with our wasteful overuse of synthetic fertilizers. And coming up fast on the outside is climate change.

Q *As the climate shifts, can't species just migrate to more favorable areas?*

A It's already happening. Joshua trees are moving northward out of Joshua Tree National Park. Fish in the oceans are migrating to cooler waters. But species can move northward only so far. At a certain point, ecosystems simply disassemble, and the surviving species will reassemble into something hard to imagine.

Q *You've called for "re-greening" the planet — namely, restoring ecosystems — to put the brake on climate change. How would that work?*

A A significant portion of the excess CO_2 in the atmosphere is from centuries of destruction and degradation of ecosystems. A concerted effort to do ecosystem restoration around the world could pull about half a degree of warming out of the system before it actually happens. For example, tropical forests can be brought back on marginal agricultural land. Native species can be reintroduced to places where they've vanished.

Q *How do you envision funding ecological restoration on a meaningful scale?*

A There simply has to be an appropriate price for carbon that reflects its actual cost in terms of the climate disruption that it creates. And if we all pay a bit more for fossil fuels — which means we are less wasteful of them — some of the revenue from that could go into these projects. I don't think it takes a lot.

— RICHARD SCHIFFMAN

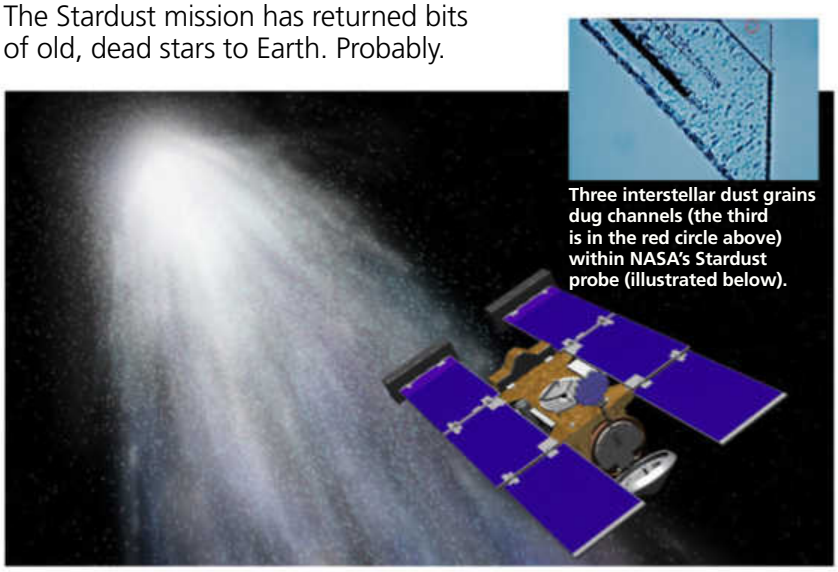
DID YOU KNOW? **Step aside, spider silk: Researchers report in the *Journal of the Royal Society Interface* that limpets' teeth actually have the record for strongest natural material. The marine snails' teeth hold up against constant scraping across rocks in search of food and boast a tensile strength three to five times that of spider silk.**

FROM TOP: SLOBODAN RANDJELOVIC; COURTESY OF THOMAS LOVEJOY; MYN/CARSTEN KRIEGER/NATURE PICTURE LIBRARY

THE CRUX

Capturing the First Interstellar Travelers

The Stardust mission has returned bits of old, dead stars to Earth. Probably.



Three interstellar dust grains dug channels (the third is in the red circle above) within NASA's Stardust probe (illustrated below).

Our solar system began as a swirling cloud of dust and gas, the remainders of exploded stars. In 1999, scientists launched a spacecraft called Stardust to take a better look.

Stardust rocketed more than 3 billion miles around the solar system. Throughout the mission, particles of dust smacked into the spacecraft's sample collectors, where they became lodged in an ultralightweight spongy material called aerogel. Seven years later, the probe returned to Earth, landing in Utah with its tiny precious cargo.

Last year, scientists announced that seven of those teensy dust particles — stuck in the Space Age gel — seem to come straight from the solar system's original embryonic cloud, based on initial analysis. They are likely interstellar dust particles: the ashy remains of ancient suns, stars that died fiery deaths billions of years ago. The largest of these particles are just microns (thousandths of a millimeter) across: All seven could fit in the period at the end of this sentence.

"This is the first baby step in exploring a new kind of extraterrestrial material," says lead researcher Andrew Westphal of the University of California, Berkeley. His team still needs to double-check the particles' origins. "We haven't done it yet, not because we're lazy or because the instruments don't exist," he says, "but because we aren't yet confident that we can prepare these samples for analysis without losing them!" — SARAH SCOLES

INBOX

Details, Please

June's "Death in the Lab" prompted questions from a reader.

I enjoyed the article and thought it was well written, but I would have appreciated some context and perspective on how often that specific act (transferring a pyrophoric liquid from one bottle to another) happens in labs, and how often the recommended safety rules for doing that are observed. One can find many examples where recommended safety rules are ignored, where it is the norm. **David Cox** *Syria, VA*

FROM TOP: NASA/GODDARD SPACE FLIGHT CENTER; UC BERKELEY/ANDREW WESTPHAL

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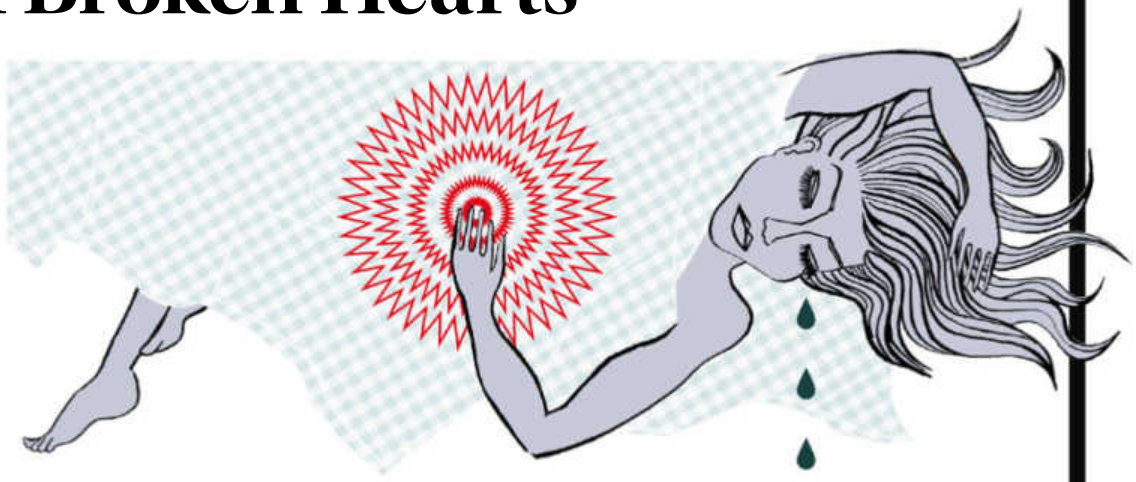
Night of Broken Hearts

A woman's extreme abdominal pain points to gallstones. But why is her heart rate going through the roof?

BY **ELIEZER J. STERNBERG**



Beep. Beep. Beep. My pager sounds so much louder at night. The day's commotion of physician rounds, family visits and discharges disappears into the quiet stillness of the night shift. The pager's alarm-clock insistence, grating at the best of times, now bursts upon my eardrums like the siren of a squad car.

"Patient having 10/10 abdominal pain," the message reads. "Can you come up and see her?"

Like fatigue or shortness of breath, abdominal pain is one of those symptoms that could represent anything. It could be as benign as constipation or as serious as a surgical emergency.

I study Elaine's chart. She's 41 and in good overall health, despite high cholesterol and gallstones. She was admitted with abdominal pain this morning, with the presumption that she had an inflamed gallbladder. However, an ultrasound was inconclusive.

"How are you feeling?"

Elaine turns her head; she doesn't need to tell me. Her thin frame lies straight as a board, arms stiffened at her sides. She is drenched in sweat, the beads on her forehead coalescing with tears as they slide down her cheeks. When patients are in terrible pain, they'll tell you it's the worst pain they've ever felt or, if given a scale, tell you it's a 10 out of 10. But there is a certain point at which pain becomes unspeakable.

She is drenched in sweat, the beads on her forehead coalescing with tears as they slide down her cheeks.

Her blood pressure is fine, no fever. Her respiratory rate is 30 breaths per minute. Most worrisome, her pulse is 140 beats a minute. While lying in bed, yours is about 70.

"Can you show me where it hurts?"

With her clenched fist, Elaine motions to her upper abdomen. I place my hand on her belly, just below the rib cage. "Here?"

She squeezes my hand in acknowledgement. I press gently. There's a strategy to this. If an organ is tender, it's likely inflamed, and that may mean that surgery is in order. If the right lower quadrant is tender, the appendix may be the culprit. If the right upper quadrant hurts, we might suspect the gallbladder.

As I apply pressure to each quadrant, I gauge Elaine's reaction to see where the pain is worst. Since I know she has stones in her gallbladder, I expect the right upper quadrant to be most tender. But it isn't. What's puzzling is that she winces equally no matter where I press.

The rest of the exam is normal, aside from her pounding heart. It's going remarkably fast, but excruciating pain can raise your heart rate.

"Elaine, I'm going to figure out what's happening to you."

I take her hand. She locks eyes with me, silently pleading.

SIGNS OF PAIN

Despite my promise to Elaine, I'm more confused than when I went in. A patient admitted for gallstone-related pain has worsening abdominal pain. This should be an easy call. But the lack of a pattern of pain clouds the picture. Staring at the ceiling as I walk, I mentally shuffle the possibilities. Is it her bile duct? A perforated stomach ulcer? Her pancreas?

"Let's get a set of labs," I say to Carla, a nurse, "and an abdominal CT scan." Translation: Let's snap a picture and hope the answer will reveal itself.

Carla calls Radiology while I order blood tests for the liver, gallbladder and pancreas. Tests for infection and inflammation. Medications for pain and nausea. But what else?

I remember a lesson I learned

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early on: Most of the time, patients will give you all the information you need to make the correct diagnosis. Elaine didn't have the strength to give me much description, but I have the physical findings. Disease leaves behind a crime scene strewn with evidence. I just have to become that detective who connects the black footprints to the smell of ash in the air and identifies the killer as the chimney sweep.

So I go back to the evidence, back to Elaine's room. "Can you show me again where the pain is worst?" I want to see if the location is consistent. With her fist clenched, she motions to the upper abdomen.

I catch Carla back at the nursing station. "Let's do an EKG and cardiac enzymes."

"You think she's having a heart attack?" she says. "I thought it was more abdominal pain."

"It's possible. We have to at least rule it out."

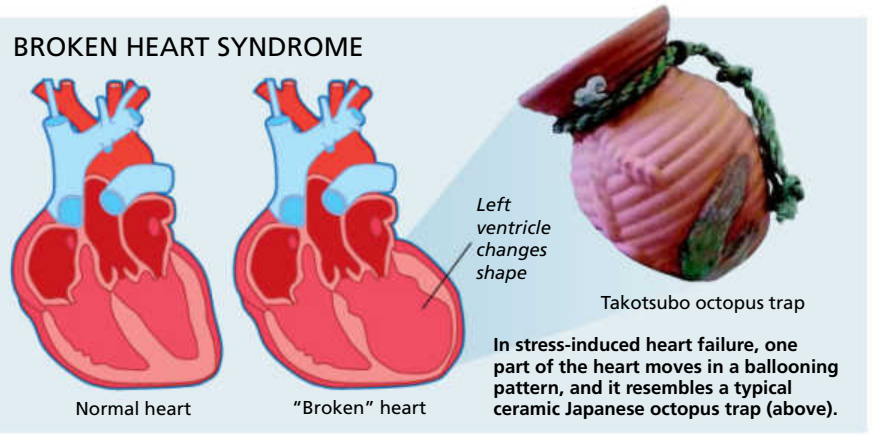
It's not uncommon for chest pain to masquerade as abdominal pain, so cardiac tests should be run on anyone in Elaine's situation, especially with her heart rate of 140. But Elaine also offered a hint.

In old medical textbooks, the placement of a fist over the chest to express pain is known as Levine's sign. It's named for the cardiologist Samuel Levine, who reported in the 1960s that many of his patients used that gesture to indicate chest pain. He was also one of the first to suggest that the pain of a heart attack can mimic that of someone who needs immediate abdominal surgery.

"Here's the EKG." Carla hands me the electrocardiogram printout. It seems clear to me. It must be a heart attack.

"Cancel the CT scan," I say. "We have to activate the catheterization lab, and she'll need to be transferred to the cardiac ICU."

I tell Elaine what's happening as she's rolled to the intensive care unit.



In stress-induced heart failure, one part of the heart moves in a ballooning pattern, and it resembles a typical ceramic Japanese octopus trap (above).

HEARTBROKEN

"This is just awful." Carla breaks the silence as we stand outside the cardiac ICU, the intensive care staff scurrying to prep for the catheterization. "I mean, first your husband cheats on you, and the next thing you know, you're having a heart attack."

"Wait, what? When did her husband cheat on her?"

"Elaine told her day nurse that she just found out he had been cheating on her for years," Carla says. "She confronted him about it a few days ago. Now she's thinking of divorcing him. So sad. They've been married over 10 years."

It's as if, at the scene of the crime, I've just uncovered a shred of the perpetrator's clothing. I pull aside the ICU doctor to share what I've learned, and together we roll the ultrasound machine into Elaine's room.

We decide to do a quick echocardiogram to check how her heart is working.

When someone has a heart attack, an echo will usually reveal that one part of the heart is not moving properly. The blood vessel to that side has been blocked, depriving the muscle tissue of oxygen, so it stops moving. However, the rest of the heart, unaffected by the blockage, should pump relatively normally.

In Elaine's case, though, the images on the screen show that her *entire* heart is moving abnormally. What's more, one area in the left ventricle pumps in a balloon pattern. It's a finding that argues against a heart attack. In fact, it suggests a diagnosis of Takotsubo cardiomyopathy, also known as broken heart syndrome.

Named after a Japanese octopus trap (which is balloon-shaped), Takotsubo cardiomyopathy is stress-induced heart failure. Extreme emotional distress can physically change the way the heart pumps. Not only is this often mistaken for a heart attack, since it can mimic the characteristic EKG and cardiac enzyme findings, but it can kill a person. No one is sure how this happens, but it's thought that the surge in adrenaline caused by grief disrupts the functioning of heart muscle cells.

In Elaine's case, her catheterization would confirm that she had no blockages in her heart. She did not have a heart attack, but that's not to say that her heart had not been broken. Physically, her heart returned to normal in a few weeks. Like any broken heart, one affected by Takotsubo cardiomyopathy needs time and supportive care to heal. D

Eliezer J. Sternberg *is a resident neurologist at Yale-New Haven Hospital and the author of the forthcoming* NeuroLogic: The Brain's Hidden Rationale Behind Our Irrational Behavior. *The cases in Vital Signs are real, but names and certain details have been changed.*

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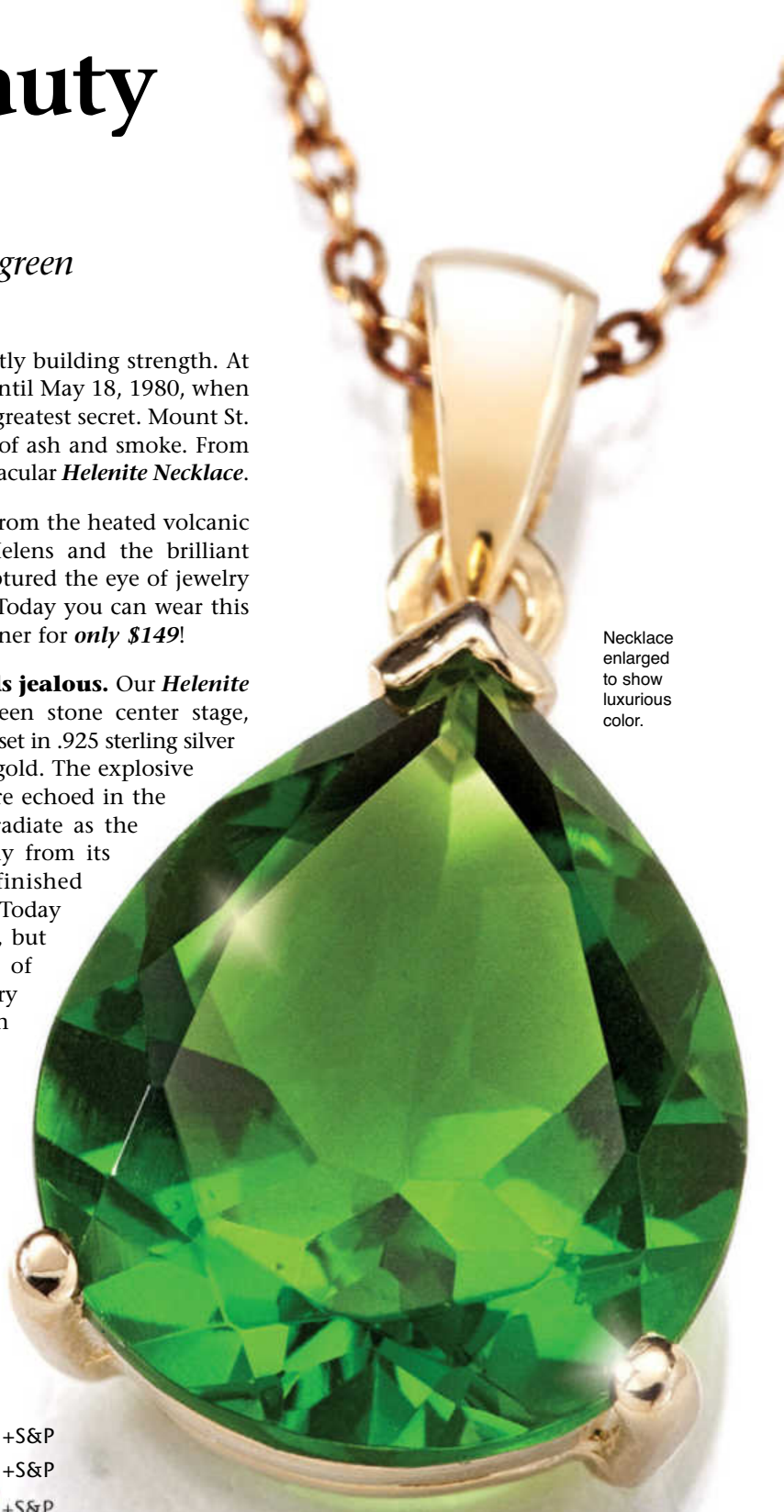

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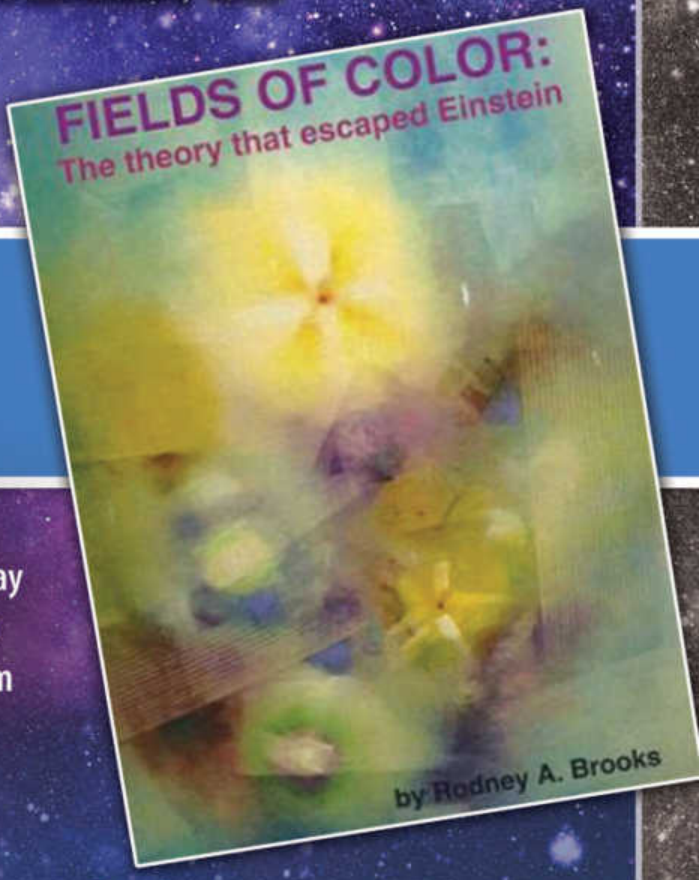

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Age & Enlightenment

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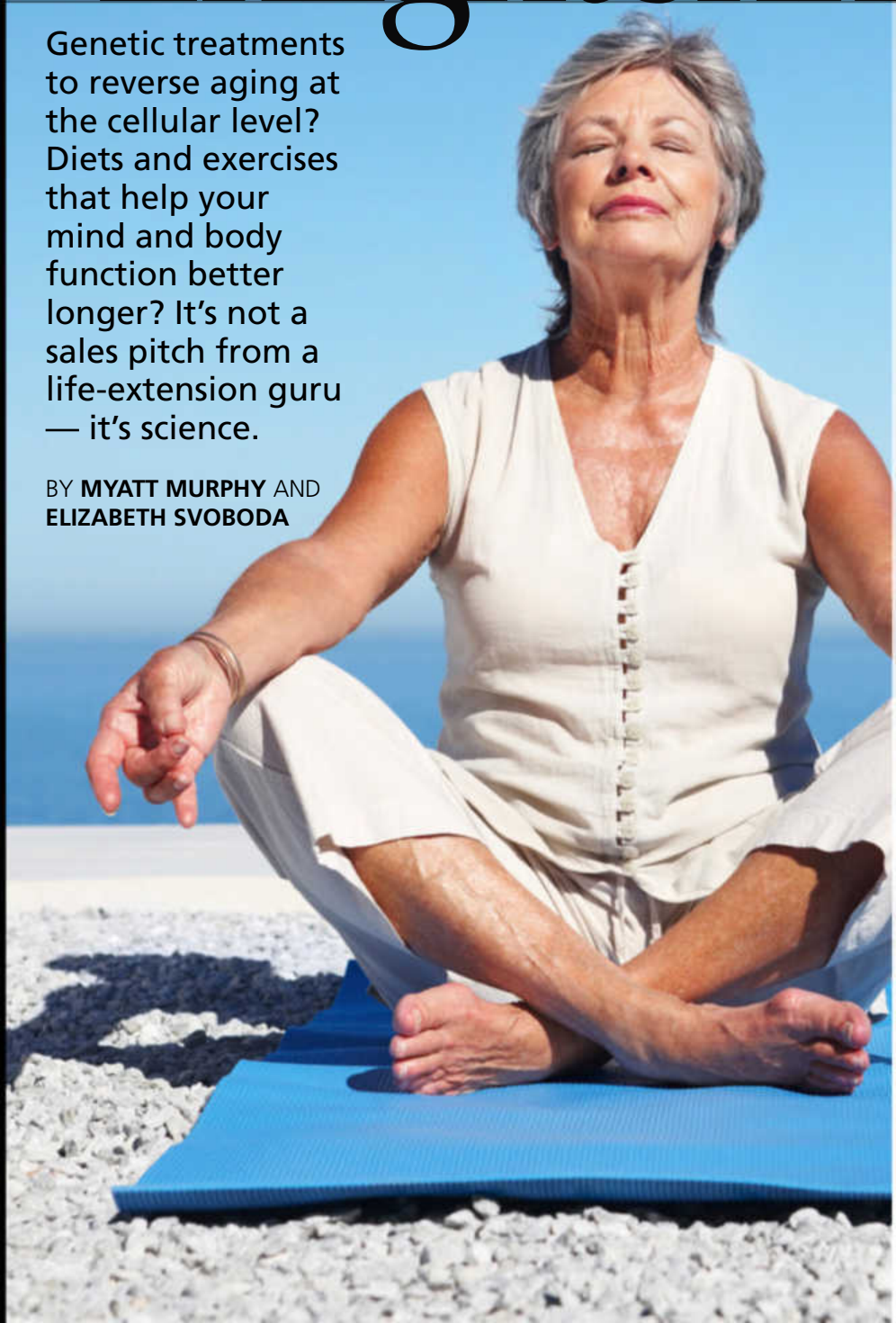
BY **MYATT MURPHY** AND **ELIZABETH SVOBODA**



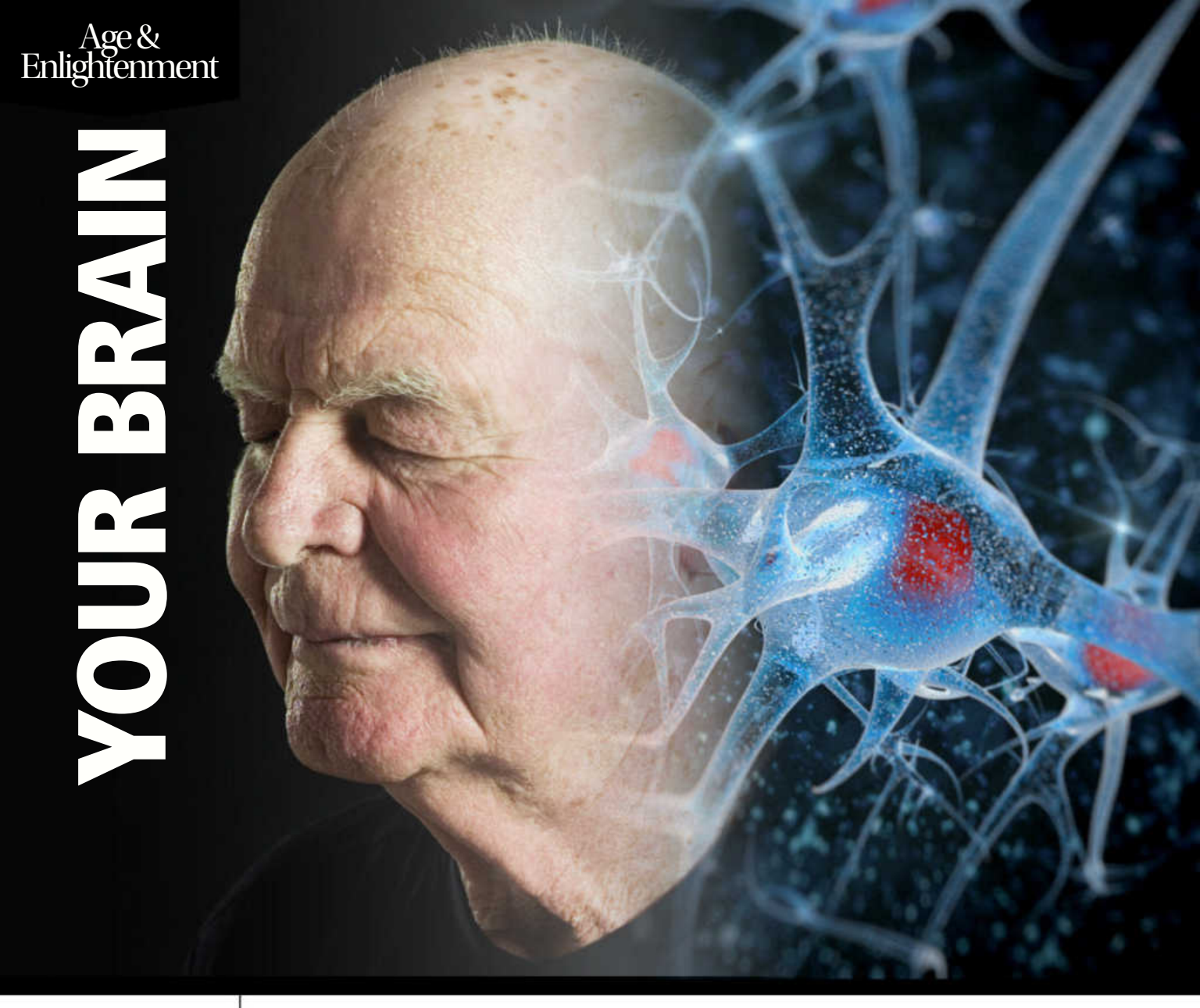
GLOBALSTOCK/ISTOCK

For civilization, there's no better time to understand aging. With roughly 10,000 baby boomers turning 65 in the U.S. every day, the "silver tsunami" is predicted to raise the national health care bill to $4 trillion in 2030. Globally, the 65-plus demographic is estimated to triple from 524 million in 2010 to about 1.5 billion by 2050.

Most of us hope to live to a vigorous old age. And to help us do that, researchers are exploring ways to manage or overcome some of the most common and vexing age-related ailments. Here you'll get a look at some of the most groundbreaking developments.

But there are plenty of self-anointed health and nutrition gurus out there, too, spouting advice about diets, supplements and exercise to a population eager to try almost anything. What sometimes gets lost in this life-extending frenzy is what science actually tells us about healthy aging. What dietary habits help you live longer? Do you have to lift weights or run marathons to keep your body in tiptop shape? Is there proof that brain training actually works? We've culled recent research to lend some scientific perspective and understand what works when it comes to healthy-aging claims.

YOUR BRAIN



Reversing Alzheimer's, Rejuvenating Brain Cells

A small but intriguing 2014 study is the first to suggest that memory loss from Alzheimer's may be reversed through a 36-point therapeutic program that includes dietary changes, brain stimulation, exercise, improved sleep and other methods that affect brain chemistry. After undergoing the complex process, nine of the 10 participants, who suffered from cognitive impairment or memory loss associated with Alzheimer's, displayed improvement in memory three to six months into the program — a joint venture between the Mary S. Easton Center for Alzheimer's Disease Research at UCLA and the Buck Institute for Research on Aging.

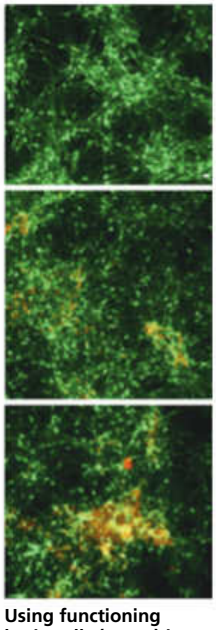
The biggest leap forward in Alzheimer's research has been in the imaging of two prominent players that build up in the brain and are assumed to be behind the disease: plaques, the abnormal clumps of beta-amyloid protein pieces found between nerve cells, and tangles, twisted threads made up mainly of the protein tau that are found within the cells.

"It used to be that you could only see the plaques through an autopsy, but now we can image beta-amyloid in the living brain to see how it changes before somebody presents clinical symptoms," says Laurie Ryan, chief of the Dementias of Aging Branch in the National

ANGELA COPPOLA/CORBIS AND VITSTUDIO/SHUTTERSTOCK

Institute on Aging (NIA) Division of Neuroscience. Although tau imaging is still in its earliest stages, Ryan hopes that such imaging will accelerate drug development and that finding a blood-based biomarker for Alzheimer's to reveal risk (much like cholesterol serves as a marker for cardiovascular risk) will change the field dramatically in terms of how doctors can diagnose the disease.

Stem cells may also unlock some of the doors that Alzheimer's and other age-related diseases close. Pick a body part, and you can bet researchers are scrambling to figure out ways to reactivate, repair — and yes, even regrow — the cells within it. But stem cells aren't being considered purely as a method to restore age-induced degradation, but as a means to prevent it. Using functioning human brain cells grown from stem cells, neuroscientists at Massachusetts General Hospital have most recently discovered how to create in a petri dish the same plaques and tangles associated with Alzheimer's. According to lead researcher Rudolph Tanzi, this key model will help accelerate research on Alzheimer's and other neurodegenerative diseases that will be both more thorough and less expensive.



Using functioning brain cells (green) in a petri dish, researchers created the same amyloid plaques (red, yellow) associated with Alzheimer's.

Meanwhile, a protein commonly found in the blood of young mice (and humans) may hold the key to rejuvenating brain cells. According to a study published in *Science*, the protein, called growth differentiation factor 11 (GDF11), can reverse the decline in blood vessel volume seen in the brains of aging mice and enhance neurogenesis (the generation of new nerve cells). But how these findings may translate into potential therapies for the mind remains to be seen.

"Research has shown that there are steady declines in a number of different cognitive functions, such as memory and speed of processing, from young adulthood to older age," says Molly Wagster, the chief of the Behavioral and Systems Neuroscience Branch in the NIA's Division of Neuroscience. "However at the same time, there is an improvement in cognitive function as we age in some domains, including vocabulary and semantic understanding."

Wagster says research over the past several decades has shed new light on what may cause age-related cognitive decline and what is no longer considered to be true. "It was once believed that we lose significant numbers of nerve cells as we age, particularly in the areas important for learning and memory," she says. "But data now shows we lose less than previously thought, that in fact, our brains are capable of neurogenesis both in adulthood and even into older age." —MM

Healthy Aging Claim

An insatiable sweet tooth could lead to dementia.

It's possible.

Diets high in fructose (fruit sugar) and sucrose (table sugar) can induce metabolic changes associated with Type 2 diabetes. And having diabetes later in life jacks up your risk of Alzheimer's disease by 40 to 50 percent, according to a meta-analysis of studies in the 2014 World Alzheimer Report.

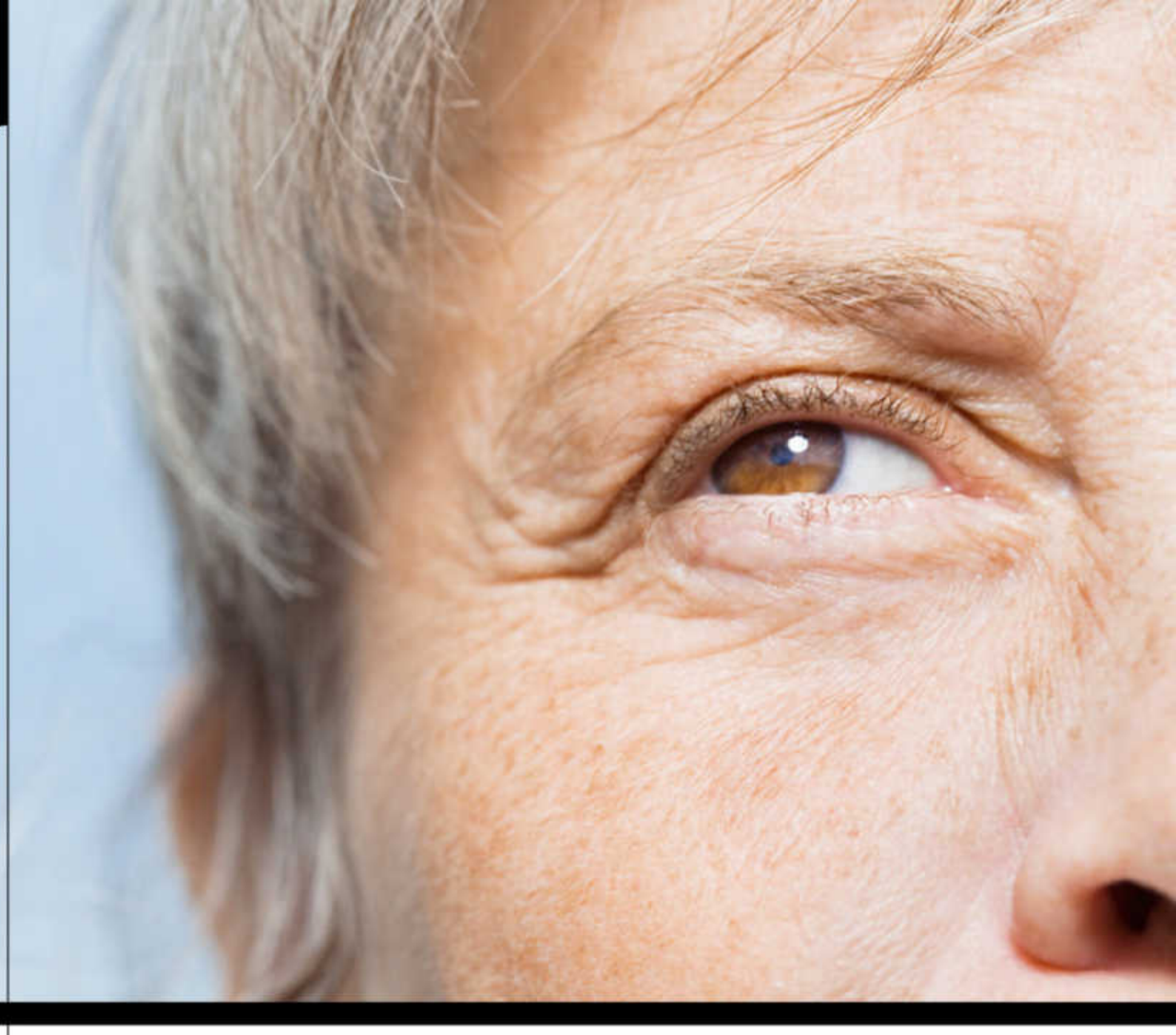
How could a hard-core snacking habit damage your brain? As millions of cake and candy lovers can attest, frequent sugar binges tend to bring on weight gain. Fat cells grow larger when we gain weight, and the larger they get, the less sensitive they are to the hormone insulin, which cues the cells to take up glucose from the bloodstream. Decreased insulin sensitivity causes blood sugar levels to remain higher after a meal. If your average blood glucose levels climb high enough, you'll be diagnosed as diabetic — and that's bad news for your cognitive health.

Insulin is critical to cognitive health because it kicks off a biochemical cascade that protects brain cells, and when the cells become insulin-resistant, they may begin to falter. If the situation gets bad enough, neurons degenerate, and dementia sets in. For these reasons, "Alzheimer's [is] considered the diabetes of the brain," says neuroscientist Paula Moreira of Portugal's University of Coimbra. That's reason enough to watch your soda and churro intake. Even if you've got mental firepower to spare, is overdosing on sweets worth the risk of brain damage as you approach old age? —ES

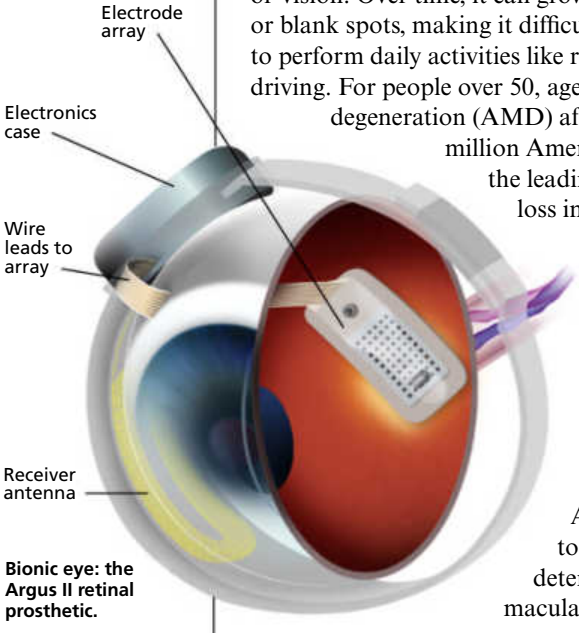
BRAIN TRAINING

New evidence suggests that brain training, the cognitive equivalent of jumping jacks, can help keep your mind sharp into old age. Johns Hopkins researchers followed more than 2,800 adults age 65 and older who attended 10 one-hour brain-training classes over the course of six weeks. Participants solved puzzles, memorized lists and did other mental exercises to hone their memory, reasoning and information-digesting skills. Five to 10 years later, most subjects maintained gains they'd made and outperformed untrained control subjects, the researchers reported in 2014. So don't let yourself become a mental couch potato. Keep up your cognitive fitness by tackling Sudoku puzzles or committing your grocery list to memory. —ES

YOUR SENSES



Seeing the Future With Bionic Vision



Bionic eye: the Argus II retinal prosthetic.

It may start slowly, as a blurred spot in your center of vision. Over time, it can grow to full-on dim or blank spots, making it difficult or impossible to perform daily activities like reading or driving. For people over 50, age-related macular degeneration (AMD) affects about 15 million Americans and remains the leading cause of vision loss in the entire Western world, according to Abdhish Bhavsar, director of clinical research at the Retina Center of Minnesota. As the name of the disease indicates, AMD occurs due to slow, progressive deterioration of the macula, a part of the eye necessary for clear, central vision.

A common type of the disease, known as neovascular or "wet" AMD, is typified by abnormal blood vessels growing under the retina; these vessels can leak and cause damage to the macula. Treatment for this type of AMD has shifted away from standard laser treatments and photodynamic therapy, a combination of light-sensitive medication and laser light used to block the growth of abnormal blood vessels. At the moment, this treatment improves vision only in a small percentage of patients.

Instead, Bhavsar says doctors are moving toward multiple new medicines and cutting-edge technologies. One medication in particular is bevacizumab, a drug used to treat advanced cancers that slows the growth of new blood cells. "In spite of the drug not being FDA-approved for use in the eye, it's probably the most common medicine used worldwide right now for treating age-related macular degeneration," says Bhavsar.

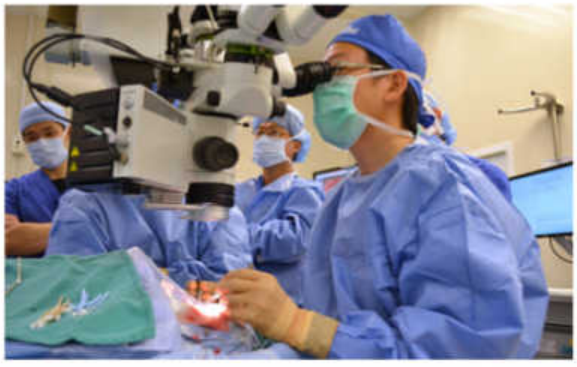
There's also the Argus II Retinal Prosthesis

TOP: XIXINXING/ISTOCK. BOTTOM: SECOND SIGHT MEDICAL PRODUCTS

System, or, as Bhavsar and others in ophthalmology like to call it, the bionic eye. "It's actually an artificial retina implanted into the weaker eye," he says of the recently FDA-approved device. A pair of camera-equipped glasses worn by the patient receives light, which is converted to a wirelessly transmitted signal and sent to an antenna in the artificial retina. The artificial retina then converts the signal into electrical impulses, which bypass damaged photoreceptors and stimulate the retina's remaining cells.

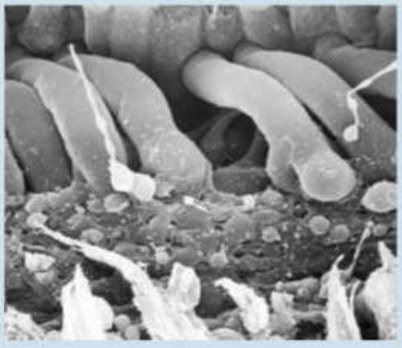
Another surgical innovation tackles presbyopia, the normal, age-related loss of near-focusing that causes many to rely on reading glasses in later years. "At about age 40, we begin to lose the accommodative ability to focus up close like we used to, and it's an unavoidable change that gradually gets worse," says Ivan Schwab, professor of ophthalmology at the University of California, Davis School of Medicine.

That's where the KAMRA corneal inlay, the first device of its kind to win FDA approval, may help. Inserted into the eye, the removable implant acts like a camera aperture, adjusting the depth of field when needed. So far, more than 80 percent of implanted patients experienced 20/40 vision or better for a period of three years, making the easily reversible option a less permanent alternative to procedures such as LASIK. —MM



Duke Eye Center surgeon Paul Hahn (top) implants the Argus II retinal prosthetic into Larry Hester (above), age 66. Hester was one of the first people to receive the FDA-approved implant.

CLOCKWISE FROM BOTTOM LEFT: SHAWN ROCCO/DUKE MEDICINE; SAMIHA KHANNA/DUKE MEDICINE; GORAN BREDBERG/SCIENCE SOURCE; MARK BOWDEN/ISTOCK



Inner-ear hair cells, seen here via scanning electron micrograph, become swollen and damaged due to age-related degeneration.

Breakthrough Drug to Reverse Hearing Loss?

Doctors call it presbycusis, but you've heard it called another name: age-related hearing loss. Even though experts know the condition is primarily due to the loss of hair cells in the inner ear (among other factors), they remain no closer to figuring out how to prevent it.

One reason is that it's impossible to tell the difference between age-related damage and damage due to prior noise exposure, says Frank Lin, associate professor of otolaryngology and epidemiology at Johns Hopkins University School of Medicine. "All we do know is that many cells within the inner ear are post-mitotic, which means once they're destroyed, the body can't regenerate them."

There are no proven pharmacologic therapies for age-related hearing loss, but that may soon change. One area researchers are looking into is symptomatic therapies that could boost hearing on a daily basis. "Imagine a drug that could act like Viagra in the inner ear," says Lin, who notes that clinical trials are already underway to study the effects of such disease-modifying drugs. One such drug — known as a Kv3 potassium channel modulator, in development by U.K.-based Autifony Therapeutics — may help improve neuron function in the part of the brain responsible for processing sounds.

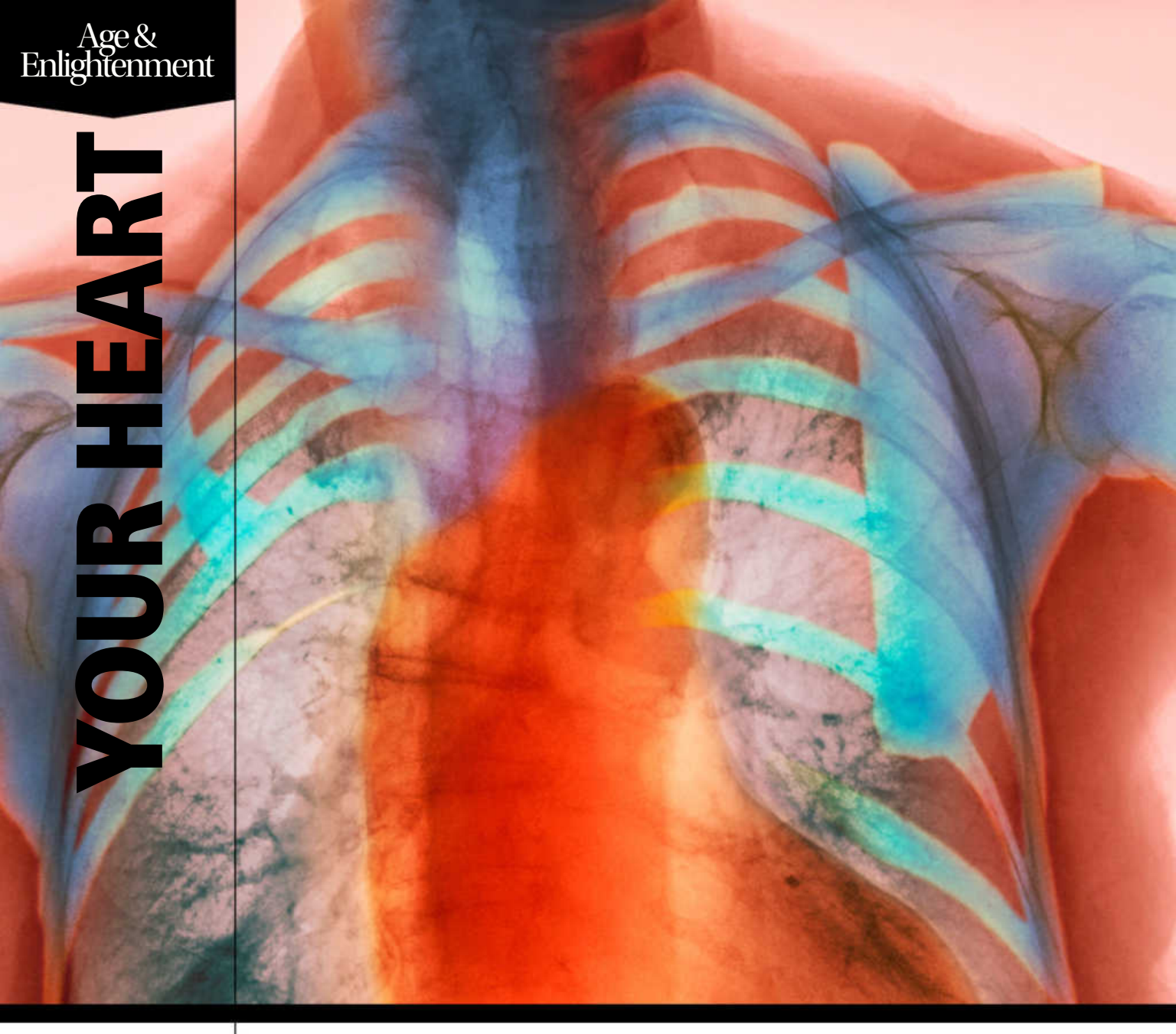
"There's also a push to develop neurorestorative therapies that can repair hair cells within the inner ear," says Lin. One clinical trial involves the drug CGF166, a one-time gene therapy, which, if proven successful in humans, could regenerate new hair cells within the cochlea that can signal the part of the brain that processes sound. —MM

FROM THE LAB

REST UP

You know it's important to get the requisite eight hours (or at least seven) per night, but what's more surprising is why it's so important. People who have trouble sleeping are two to three times more likely to be depressed, a condition that weakens late-life physical defenses and accelerates mortality. When cognitive behavioral therapy, a form of talk therapy, was designed to instill better sleep habits — like waking up at the same time every day and confining sleep to bedtime only — it helped vanquish stubborn insomnia, according to data from an ongoing study at Toronto's Ryerson University. Fully 87 percent of patients whose insomnia vanished saw their depressive symptoms improve as well. —ES

YOUR HEART



Mouse Protein Helps Heart Muscle

Time can be unkind to all the muscles in your body, especially the heart. "As it ages, it gets bigger, thicker and stiffer due to hypertrophy, a process that causes its muscle cells to become larger," says Michael Lauer, director of the division of cardiovascular sciences at the National Institutes of Health's National Heart, Lung, and Blood Institute. "Although we understand heart hypertrophy increases the risk of premature death and other forms of heart disease, we still don't fully understand how to reverse it, but we may be getting there."

In 2013, researchers reported that they were able to cure hypertrophy in mice by surgically merging the circulatory systems of an older mouse with a younger mouse. "The process, known as heterochronic parabiosis, managed to reverse hypertrophy in the older mouse after just four weeks," says Lauer. But they're not sure exactly what's driving the changes.

The GDF11 protein commonly found in the blood of young mice (the same protein that enhanced neurogenesis in aged mice) and placed in individual older mice was thought to have the same reversal effect on hypertrophy; however, more recent research suggests another molecule besides GDF11 may be at work. —MM

BRANDON BROLL/SCIENCE PHOTO LIBRARY/CORBIS

From Mice to Men

Aging research may be on the rise, but it does have its own set of unique limitations in terms of how quickly discoveries in the lab turn into human clinical trials. "There's a lot of grumbling, both in the general public and the scientific community, about how often we cure diseases in mice that never translates when we try those cures in humans," says Felipe Sierra, director of the Division of Aging Biology at the National Institute on Aging.

Part of the problem, he says, is that the incidence of many human chronic diseases rises with age, yet many researchers prefer using young mice because of the pressures of being published and getting funding. Since most grants are usually only for a four- to five-year period, using younger mice is not only less expensive, but it avoids the delay of waiting for an animal to age.

"The physiology is quite different, so it's not surprising that a drug may show efficacy in a young, resilient animal that has the ability to fight off things, but that same cure may not work in an older animal," says Sierra. One of his greatest goals is to convince people of the importance of using both younger and older animals in research that is meant to be translatable to aging humans. "It may cause delay in the early stages, but it will save money and lives in the long run," he says. —MM

Healthy Aging Claim

Can eating like a bird add years to your life?

Don't count on it.

Since the mid-20th century, researchers have noted that calorie-restricted lab animals live longer than their well-fed counterparts. Naturally, some self-proclaimed health gurus have seized on these studies as evidence that humans could reap the same benefits by slashing their food intake. That prospect has inspired calorie-restricted diets that feature arcane ingredients like brewer's yeast and psyllium husk and may total less than 1,200 calories per day.

Despite these dieters' herculean efforts — forgoing dessert in favor of processed whey protein is a pretty drastic move — there's still no solid evidence that slashing calories will extend human lives.

Rats do live about 40 percent longer on a calorie-restricted regimen, and roundworms live up to 50 percent longer. But evidence is mixed in monkeys, whose responses presumably mimic ours. In a University of Wisconsin study published in 2014, older rhesus monkeys that ate spartan diets for years were less likely to die, while scientists at the National Institute on Aging (NIA) reported in 2012 that calorie-restricted rhesus monkeys lived about as long as those on a normal diet.

Calorie restriction does seem to forestall aging, at least somewhat, on the cellular level. University of Washington researchers have found that a calorie-restricted diet reduces the activity of a cell-signaling protein called TOR-1 that may speed up cell aging. And scientists at Harvard Medical School, the NIA and elsewhere have shown that caloric restriction drives expression of proteins called sirtuins, which help promote cell survival.

Such research may help scientists understand the mechanisms that underlie aging and identify promising drug candidates that mimic the health-promoting effects of caloric restriction, says NIA's Felipe Sierra.

Right now, though, "people are subjecting themselves to these very harsh regimes, [but] I don't suggest anyone follow any of the leads that we have," Sierra says. Essentially, caloric restriction involves a lot of pain for no sure gain. —ES

Healthy Aging Claim

An active social life helps you live longer.

True.

Maintaining a strong social network may foster good health in part because support from sympathetic friends and family helps cushion the impact of life's blows. When you lead a less anxious life, you're less prone to certain chronic conditions, such as cardiovascular disease.

George Vaillant, a psychiatrist who directed a study that has monitored a group of former Harvard students since 1939, writes, "It is social aptitude, not intellectual brilliance or parental social class, that leads to a well-adapted old age."

Barring a major drinking binge, being the life of the party is good for you. In fact, highly social people have a 50 percent better chance of survival than loners over a period of several years, according to Brigham Young University psychologist Julianne Holt-Lunstad. She analyzed over 100 studies on the long-term relationship between social activity and health. The studies followed subjects for an average of seven and a half years. A misanthropic lifestyle, she reported in *PLOS Medicine*, could be as unhealthy as skipping exercise or smoking over a dozen cigarettes a day. —ES

FROM THE LAB

LEND A HELPING HAND

The more you do for others as you age, the more you do for yourself. Volunteering eases stress, which, in turn, lowers the risk of disease and mortality, particularly in those with cardiovascular disease. People older than 70 who volunteer for more than 100 hours a year report better health than senior non-volunteers, University of Minnesota researchers reported in 2005. Other studies show that committed volunteers have less chronic pain. Volunteering also gives participants a sense that they are valued and needed, which may ward off thoughts of being worn out or useless, says psychologist Benjamin Gottlieb of the University of Guelph in Ontario. —ES

LEFT: HERO IMAGES INC./CORBIS. RIGHT: JOHN LUND/MARC ROMANELLI/BLEND IMAGES/CORBIS

YOUR BODY

Building (and Rebuilding) Muscle

When it comes to your physique, it's known that with age, hormone production changes, our bodies begin storing more fat, and you lose between 3 and 8 percent of lean tissue mass per decade starting at around age 30.

"Many people that have maintained the same weight throughout their lives are not fully aware how their body composition has changed — until it unfortunately becomes unavoidably evident," says Luigi Ferrucci, scientific director of the National Institute on Aging and former director of the Baltimore Longitudinal Study of Aging, America's longest-running scientific study of human aging.

Some of that process can be reversed through exercise and hormone therapy, but your bones are another matter. "You can only build your bone mineral density up until around age 25 to 30," says Elizabeth Matzkin, surgical director for women's musculoskeletal health at Brigham and Women's Hospital in Boston. "After that, what you have is what you have, and anything you do from that point forward (including exercise) may maintain it — but you can't build them to be any stronger."

Current research is looking at why inhibiting certain molecules, such as mouse protein Stat3, promote muscle regeneration in mice and how to engineer orthopedic implants from stem cells to replace damaged cartilage and bone, but the results of that effort aren't expected to be necessarily aimed at the old. As with other parts of the body, such as the ears or the lungs, it can be difficult in orthopedics to separate the effects of pure aging from the effects of long-term wear and tear, Matzkin notes. She adds that a lot of what's emerging in orthopedics is for the moment being targeted to treat those with muscle-wasting diseases, as well as a younger population with injuries due to athleticism. —MM

SEBASTIAN KAULITZKI/SHUTTERSTOCK

The Layout to Longevity

If you're waiting for science to concoct a magical elixir to extend life span, you may end up wasting the rest of your life in vain — for now.

"There are a lot of disparate theories about what could have a profound impact on aging and age-related processes, but at this point, we simply do not have evidence-based strategies to significantly change our life expectancy that come in the form of a pill," says Ronald DePinho, professor of cancer biology and president of the University of Texas MD Anderson Cancer Center. However, science has proven that a few specific tactics can dramatically increase your life expectancy and reduce age-associated diseases.

Exercise turns hours into years: Engaging in physical activity for 2.5 hours at a moderate intensity (or 75 minutes at a vigorous intensity) each week can increase your life expectancy by 3.4 years. Choose to do only half that amount, and you'll still add 1.8 years to your life.

Manage your stress: One common thread among all long-lived animals appears to be that their cells — and in some cases, the animals themselves — are more resistant to a variety of stresses. "Chronic unrelenting stress is an accelerant for the aging process," says DePinho. So whether it's trying a new hobby, getting more sleep, talking to a therapist or stopping to take a deep breath once in a while, whatever helps reduce your stress will increase your time on Earth.

Watch your body mass index (BMI): "Obesity creates a chronic inflammatory state that drives free radicals, fast-tracks aging and increases your risk of developing many age-related diseases," says DePinho. The solution: maintaining an ideal body weight through a simple, balanced diet and minimizing processed foods in favor of fruits, vegetables and other healthier foods. Ideally, your BMI (determined by dividing your weight in pounds by height in inches squared, then multiplying by a conversion factor of 703) should fall between 18.5 and 24.9. —MM

Example:
[150 pounds ÷ (68 inches)^2] x 703 = 22.8 BMI

Healthy Aging Claim

Exercise is the fountain of youth.

Maybe.

While exercise is no panacea, it does confer plenty of benefits as we age. When Cardiff University epidemiologist Peter Elwood tracked the health outcomes of more than 1,600 people older than 45, he identified regular exercise as a key habit that reduced people's risk of chronic conditions, such as diabetes and vascular disease in old age.

"Exercise is one of the more important healthy behaviors and one of the things we can modify," Elwood says.

Regular exercisers enjoy a mental payoff as well as a physical one. Aerobic workouts not only stop brain shrinkage, but they also can help the hippocampus grow, according to University of Illinois research. And perhaps as a result, adults who routinely exercise are less likely to develop dementia, according to a 2014 study from the University of Cambridge.

But just walking around the block once in a while is not enough. You should strive to exercise five days a week for at least half an hour each day.

To stick to this kind of regimen, "try to translate half an hour [of exercise] into your normal activities. Walk up the stairs rather than taking the elevator," Elwood says. —ES

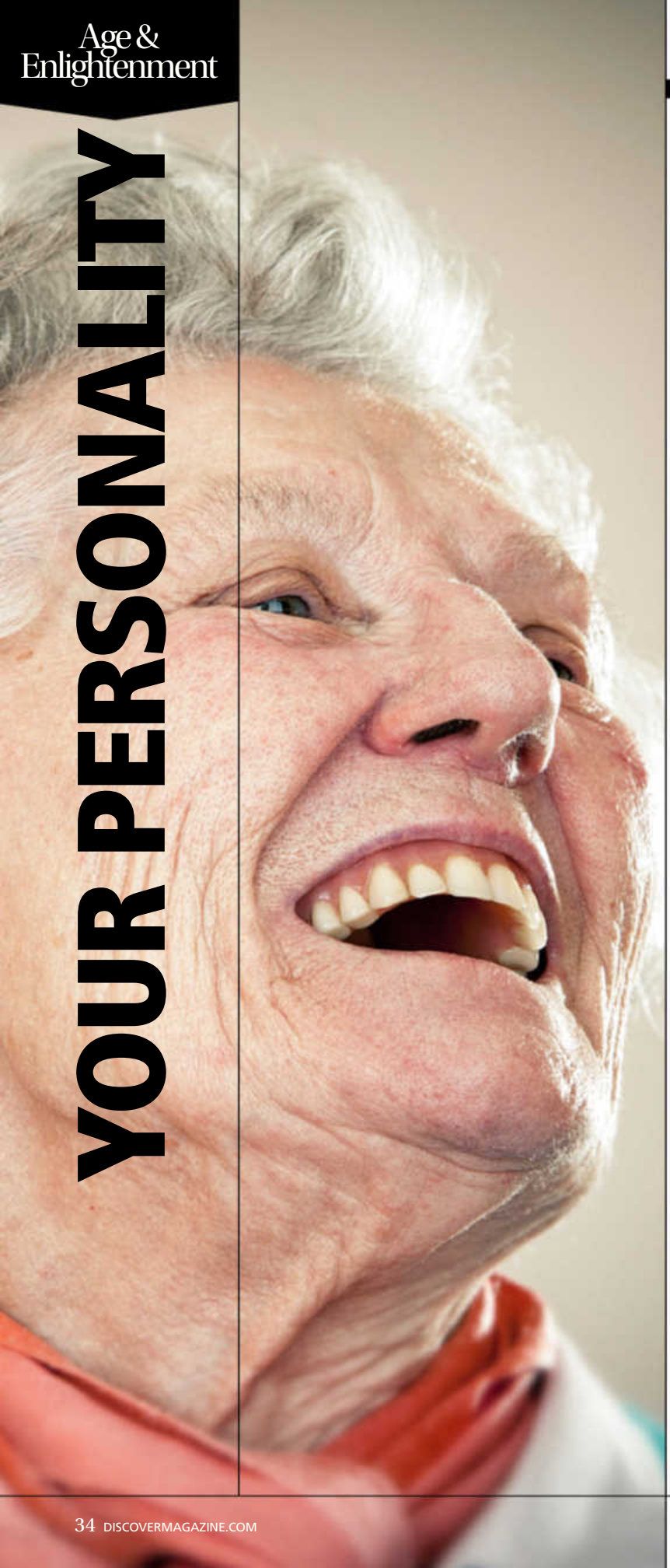
FROM THE LAB

RAISE A GLASS (BUT NOT FOUR)

Red wine contains substances that may delay aging. These include a plant-produced chemical called resveratrol, which spurs cells to increase production of sirtuins, the proteins that promote cell survival. A University of Connecticut study suggests that resveratrol helps stave off heart disease, and another study suggests that antioxidants like those found in red wine protect blood vessels from premature damage. But drinking too much worsens conditions like diabetes and high blood pressure, and may cause cancer and liver damage. National Institutes of Health experts advise that women consume no more than three drinks in a day and seven per week; men should not surpass four in a day and 14 per week. —ES

FROM LEFT: 68/OCEAN/CORBIS; MONKEYBUSINESSIMAGES/ISTOCK; COBICOINC/ISTOCK

YOUR PERSONALITY



Aging With Attitude

From his work on the Baltimore Longitudinal Study on Aging (BLSA), Luigi Ferrucci has witnessed firsthand that, for everything we currently know, the process of aging remains as enigmatic as it is inevitable. And what knowledge we have gained over the years can sometimes be easily overturned.

"For example, we used to believe people became grumpy as they got older. But an analysis of long-term data from the BLSA discovered that an adult's personality generally doesn't change much after age 30," says Ferrucci. "In fact, people who are happy when they're younger are likelier to be the same when they're much older."

It turns out "grumpy old men" — or women, for that matter — may be gruff not because of age, but because they're set in a personality shaped by their youth during times when war, poverty and other harsh experiences were more common. "It also suggests that significant changes in personality may not be due to aging," says Ferrucci, "but could be a sign of disease or dementia instead."

The BLSA has been connecting the dots on the physical and cognitive changes that take place as we age since 1958. In that time, the study has been the basis for more than 800 scientific papers on aging, papers that have expanded our understanding of the relationship between aging and cardiovascular health, metabolism, psychology and cognition.

It also remains hard at work on a project called IDEAL — Insights into the Determinants of Exceptional Aging and Longevity — that hopes to understand "exceptional agers," individuals 80 and older who are healthy and disease-free. If successful, it could be yet another tool to find solutions to age-related health issues, as well as unravel the mystery of what causes us to age in the first place. —MM

Myatt Murphy *has written numerous articles and books on health, fitness and medicine.*

Healthy Aging Claim

Your personality affects how well you age.

Actually, yes.

The grade-school Pollyanna who always turned in her homework may have had the right idea from a healthy-living standpoint.

In a University of California, Riverside meta-analysis of 20 published studies, conscientious people were more likely to live longer, which makes sense: If you're good at keeping promises and showing up on time, you'll probably be good at sticking to healthy diet and lifestyle habits.

An easygoing temperament may also confer a survival advantage. Studies of centenarians have found they're more laid back than the general population and show more optimism about the future. On the other hand, people with pessimistic tendencies are more susceptible to conditions like high blood pressure and depression.

But if you're a worrier or a dyed-in-the-wool pessimist, take heart. You can teach yourself to observe habitual negative thoughts and reframe them in a way that's more positive but still realistic, says Stanford psychologist Carol Dweck. For instance, if you're convinced you'll die young from cancer because it runs in your family, you can instead opt to focus on how you're minimizing your risk by adopting healthy lifestyle habits and having regular checkups. Changing the way you look at the world can shift your temperament, which, in turn, may improve your mental and physical health later in life. —ES

Elizabeth Svoboda *is a science writer in San Jose, Calif., and author of* What Makes a Hero?: The Surprising Science of Selflessness.

GRADYREESE/ISTOCK

The 7 Pillars of Aging

While many researchers are seeking new ways to combat age-related issues one at a time, some experts in the field of geroscience — the study of how aging causes disease — are uniting to develop preventive and therapeutic approaches to fight multiple diseases.

"We've known that aging is a major risk factor for most chronic diseases for some time, but recently, we've gained a better understanding of the aging process's basic underpinnings, which has allowed us to extend both life span and health — in animals at least," says Felipe Sierra, director of the Division of Aging Biology at the National Institute on Aging. "There's only so much we can gain in terms of disease-free longevity by curing individual diseases like cancer and Alzheimer's one at a time, but if we can address the issue of aging, then we could potentially delay and diminish them all at once."

That led Sierra in 2011 to form the Trans-NIH GeroScience Interest Group, which at a recent summit had leading scientists identify seven highly intertwined processes that promote aging:

1. **Adaptation to stress:** How individual and environmental stressors affect our physical and psychological well-being over time.
2. **Epigenetics:** How our environment can affect gene activity.
3. **Inflammation:** The body's natural response to a range of conditions, although chronic inflammation plays a contributing role to accelerated aging and chronic disease.
4. **Macromolecular damage:** The causes and effects of damage over time to the large molecules that comprise our bodies — DNA, for example — and which can drive the development of chronic disease and age-related conditions.
5. **Metabolism:** Metabolic changes due to aging may play a role in cardiovascular problems, neurodegenerative diseases, diabetes, cancer and other chronic conditions.
6. **Proteostasis:** The "housekeeping" process that regulates and maintains proper protein function within our cells.
7. **Stem cells and regeneration:** The adult stem cells in our bodies are well known for their ability to divide, renew and replace damaged tissue in the body.

Deciphering these defined pillars of aging is what experts like Sierra believe affect age-related diseases and could help design the genetic, behavioral and pharmacological means to decelerate aging.

Among the seven pillars, one that has inspired much excitement is metabolism, where researchers have been trying to understand why calorie restriction seems to extend the life span in mice and other animals. Is it because metabolizing fewer calories results in less oxidative damage? Could the absence of nutrients trigger certain defense mechanisms that protect the body? According to Sierra, researchers have managed to identify several molecular pathways that, if modified through medicine, could one day mimic the life-expanding effects of calorie restriction in humans, without requiring anyone to eat less.

Another pillar being thoroughly explored is the fallout from long-term chronic inflammation. Ferrucci says centenarians and others who have lived longer, healthier lives often have less inflammation. We know that many age-related diseases involve inflammation, but we don't yet know why. Nonetheless, interventions targeted to reduce chronic inflammation are also being examined closely.

We can't shut down inflammation completely, says Ferrucci. Our bodies need the short-term adaptive form, which quickly turns on and off to fight bacteria and remove debris after injuries and infections. "We need to better understand the process on a molecular level to see if we can develop a drug that only targets what's not working while leaving everything else functional," he says. "But right now, we are shooting inflammation with a nuclear bomb — and we need to shoot inflammation with a rifle."

Developing drugs to modify these processes is one area science is investigating, but it gets complex fast. Some anti-inflammatory drugs have been found to extend life in mice, but these drugs can have multiple effects, and it's not yet clear why they work. The fact that they tackle chronic inflammation could just be one piece of the puzzle, not the whole solution.

The most promising drug so far has been rapamycin, an immunosuppressant often used in organ transplants that's been shown to extend the life span of mice. "Rapamycin is already used in humans for unrelated things," says Steven Austad, scientific director of the American Federation for Aging Research and chair of the University of Alabama at Birmingham biology department. "But in mice, it has an unbelievably wide range of effects that you'd never think a single drug could possibly have, ranging from preventing Alzheimer's and cardiovascular disease to reducing cancer."

Austad says other medications have shown similar effects on extending mouse life span, including acarbose (a common drug prescribed for Type 2 diabetes), and anti-inflammatory drugs such as masoprocol and basic aspirin. While the research has a long way to go before anything translates to humans, science may finally be on the right path to understanding aging at its core.

"For the first time in history, we have theories, and the technology to measure those phenomena in living humans longitudinally over time," Austad says. "And I'm certain that in the next 20 years, science will reveal where we need to go."—MM D

A Scientist Walks Into a Bar…

What happens when genome mapping meets the ancient craft of brewing?

BY **TODD PITOCK**

BEER: ENVISION/CORBIS. HOPS: ERNIE MASTROIANNI/DISCOVER. BACKGROUND: KELLIE JAEGER/DISCOVER

Chad Yakobson checks newly received barrels at his Crooked Stave Artisan Beer Project in Denver.

BENJAMIN RASMUSSEN

On a bright autumn day at the Viceroy Snowmass ski resort, Chad Yakobson, the 31-year-old owner of the Crooked Stave Artisan Beer Project, holds a goblet of a beer he makes called Surette. Like all of Crooked Stave's styles, it's made with *Brettanomyces*, or wild yeast, a category of beer that's growing popular even as it fights a certain stigma of being overly bold. *Brettanomyces*, Latin for "British fungus," appear on beer lists as wilds, funks and the term Yakobson likes the least, sours.

The clear Rocky Mountain light pouring through the window in Snowmass Village, Colo., illuminates the goblet like a straw-colored bulb.

"It's grassy, citrusy and earthy," Yakobson says to a gathering of two dozen people who have assembled for a seminar about Bretts. "The word people like right now is 'rustic.' It has vinous characteristics, like white wine."

Almost all beer styles use domesticated yeast strains called *Saccharomyces*, and although there are long-established styles based on *Brettanomyces* — the fruit-backed Belgian lambics, for example — brewers tend to think of Bretts as mistakes, bad things that happened when you didn't control your tanks and barrels.

Crooked Stave is small, producing just 1,255 barrels in 2014. Its offices and warehouses were recently renovated so the brewery and a new large front taproom with patio space could co-exist at the same location on the outskirts of downtown Denver. But Yakobson is building a reputation, and he spends a good deal of time on the road giving talks like this one.

"You can do a lot of things with Bretts," he says. "They don't have to be sour at all. You just have to understand the science behind it."

Although beer-making has an element of artistry and intuition, brewers are turning to genome sequencing laboratories that can identify how to create certain flavors. Some of the science disciplines involved in brewing are obvious enough, like microbiology and chemistry. But others, such as archaeology and genomics, are enabling brewers to resurrect ancient brews, while guys like Yakobson explore fermentation science to take beer in new directions.

The blending of creativity with the science of beer-making is an American-led phenomenon. Such craft brewers are emerging in Denmark, Israel, Italy and even in places like England, where beer is deeply steeped in tradition. But those places have followed the bold spirit and methods of American beer pioneers, who are arguably producing the best beer in the world.

"In brewing, the Old World is too locked into their systems," Yakobson says. "Tradition trumps creativity in the beer world. I think the lack of tradition helped us."

The first American beer-makers who studied the science of the product were mass producers like Anheuser-Busch, Coors and Miller (now SABMiller). They created labs within their breweries to understand and control the process, to make sure their product tasted the same in Tokyo as it did in Topeka.

Early craft brewers, often small companies founded by home brewers who wanted to turn their passion into a business, rejected the notion of standardization, and in the process they pushed science aside, thinking of their work as art or, as they called it, craft.

In the past decade, though, artisans realized they, too, needed to turn out a consistent product as they grew in scale. They also saw that science was the key to creativity and innovation. Beer lovers want new and different flavors, and their zeal has helped propel the craft world to more than 3,400 breweries. (The Brewers Association, the leading trade group, defines a craft brewer as producing 6 million barrels or less, less than 25 percent owned by a larger alcohol beverage company and traditional in its methods.)

Now, laboratories specializing in yeast research are engaged in genomic mapping, hoping to create new hybrids or strains for different flavor effects — or sometimes just to help a particular brewery understand why a particular batch yielded a certain unintended flavor that the brewer would like to reproduce.

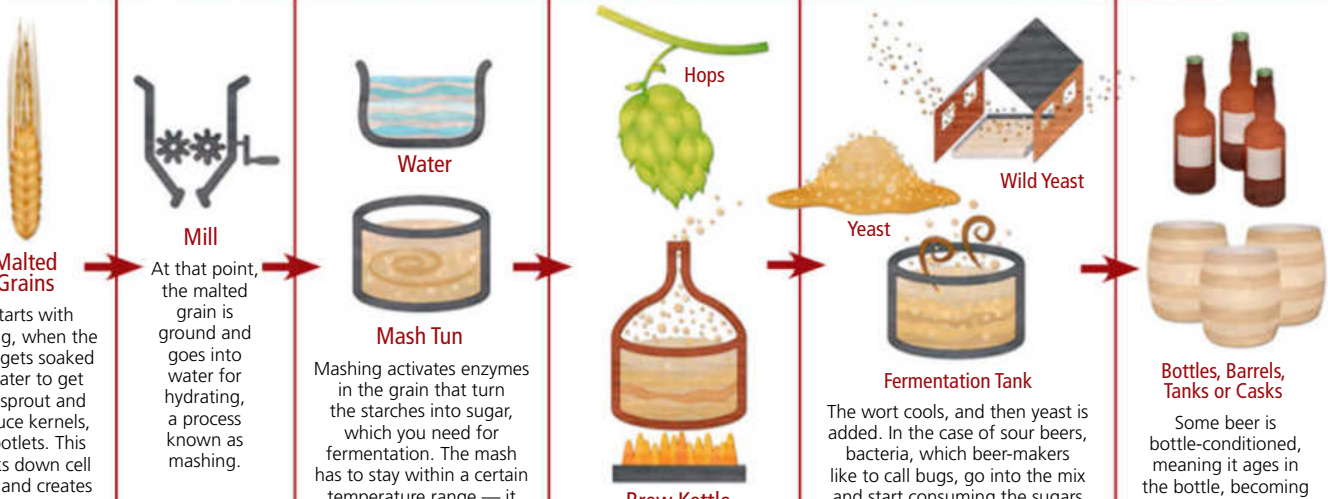
BEER 101

To understand how far beer has come, it helps to understand some beer basics.

The general ingredients are water, hops, a grain and yeast. The grain is soaked in water to sprout, then heated and dried to stop germination and isolate its enzymes. This is malting. The malted grain is ground and steeped in hot

FROM HOPS TO HAPPY HOUR

Beer has just a few basic ingredients: water, hops, a grain and yeast. The artistry of beer-making comes in the specifics of the grain and yeast and/or bacteria used, and variations on production.



BOTH PAGES AND BACKGROUND: KELLIE JAEGER/DISCOVER

water to activate enzymes that turn starches into sugar. This is mashing. The broth it creates is called wort, which gets drained and brought to a boil, then hops and other flavors are added. The wort cools, then yeast is added to consume the sugars and release carbon dioxide and alcohol. After this primary fermentation, ales are essentially done, but lagers and wild brews undergo a secondary fermentation and aging — "lagering" — some in tanks, some in barrels and others in bottles. How a brewer approaches each ingredient and step in the process determines the final product.

"Just by changing the temperature in the mash, you can adjust a beer's profile," says Gregory Deuhs, the master brewer for Peter Ballantine & Sons Brewing Co., a unit of the Pabst Brewing Co. in Milwaukee. Deuhs reverse-engineered the company's iconic Ballantine India Pale Ale after the recipe was lost in a series of ownership changes. "At a lower temperature, you can get a lighter-style beer or at a higher one, you can get a full-bodied one," he says. "[To re-create the Ballantine IPA] we did higher

Different yeast strains tolerate or respond in varying ways to different levels of alcohol, and it's these yeast strains that can create beers with vastly different flavors.

mash temperature, which resulted in more unfermentable sugars, and that gives the beer the full mouth feel and residual sweetness — which is what we want to balance off the hops."

All beer, whether it's some variety of pale ale, pilsner, porter, stout, kölsch or other, falls into one of two categories: ale or lager. *Lager* is derived from a word that means "to store," and the style was discovered by brewers who stored beer in icy, cold caves during the summer for later use. The yeasts work at lower temperatures and tend to let malts and hops dominate. Ale yeasts work at higher temperatures and can result in a wider range of esters, the flavor compounds that can give beer a whiff of banana or some tropical fruit, like lychee.

Because it's the main flavor driver, yeast is the core of the whole enterprise.

Different yeast strains tolerate or respond in varying ways to different levels of alcohol, and it's these yeast strains that can create beers with vastly different flavors.

"We're working with a live organism, so it's unpredictable," says Neva Parker, head of laboratory operations for San Diego-based White Labs, a 20-year-old yeast lab serving brewers and wine-makers with offices in four U.S. cities and Copenhagen, Denmark.

"Change one thing, and it can completely change how the yeast is going to work. We can measure the level of flavor compounds using gas chromatography. We know how many each strain produces, but we don't know why."

To learn more, in 2013 White Labs — along with a Belgian genetics lab involving the Flanders Institute for Biotechnology and the University of Leuven, Belgium — embarked on a project to sequence the DNA of about 200 yeast strains for their brewery clients.

"All the strains we carried were the same species, but there were minute differences that caused flavor differences," Parker says. "We don't have the entire genome sequence complete for each strain, but we think that when all the information comes back, we'll have a map for each one."

Certain DNA markers will point to particular flavor compounds — the esters that commonly produce banana, say, or green apple. Yeasts can create more than 500 flavor and aroma compounds that we know of. The goal, Parker says, is to understand how the yeasts' genes express themselves in the brew.

Some researchers hope that by understanding the genomes, they will eventually be able to design new brewing yeasts.

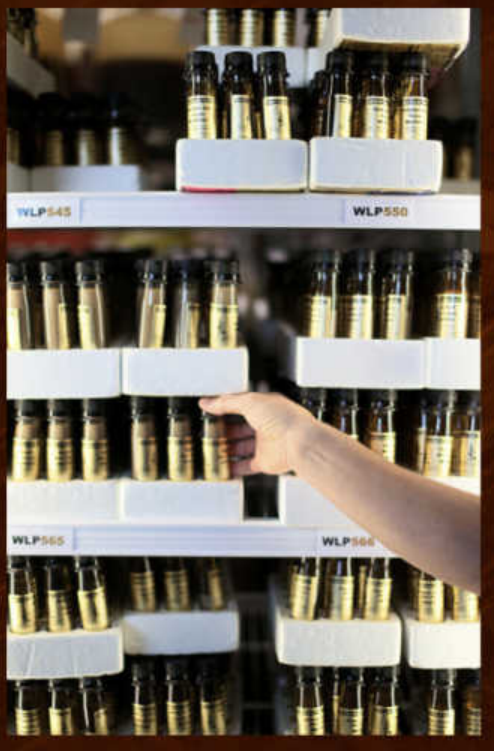
"For us, it's just about the knowledge," Parker says. "Once we know how much potential there is [in a yeast], we can start playing around with them, too, and see how environmental components can impact the expression of the flavor compounds. It could be temperature-related, which affects how yeast performs; it could be the amount of sugar given to yeast at the beginning. It could be oxygen, or nutrients a brewer would add."

FIRST DRAFTS

If genome sequencing is the future of beer, consider the information buried in the troves, and ruins, of the past.

In 2000, the University of Pennsylvania Museum of Archaeology and Anthropology hosted a dinner meant to re-create the food and beverage served at a funeral feast. The scientific director of the museum's Biomolecular Archaeology Project for Cuisine, Fermented Beverages and Health, a biomolecular archaeologist named Patrick

From left: In legend, all King Midas touched turned to gold, even food and drink, and he starved to death. Urns and jars found near his tomb in Turkey (far right) weren't golden, but some had organic residue that was analyzed and replicated 2,700 years later to make a special brew.



Clockwise from left: Neva Parker is head of laboratory operations at White Labs, which helps brewers and wine-makers better understand how yeast genes affect taste. Troels Prahl studies a yeast strain. Vials of yeast strains available for purchase are stored in refrigerators. Crooked Stave's Hop Savant uses only *Brettanomyces* yeast for its unique taste.

Some researchers hope that by understanding the genomes, they will eventually be able to design new brewing yeasts.

TOP FROM LEFT: KRISTINA YAMAMOTO; SANDY HUFFAKER (2); DUSTIN HALL/CROOKED STAVE
BOTTOM FROM LEFT: GETTY RESEARCH INSTITUTE/SCIENCE SOURCE; STEVE ESTVANIK/SHUTTERSTOCK (2)

"Dr. Pat" McGovern, spoke about the re-created beverage and entrée, spicy barbecued lamb and lentil stew.

In 1957, archaeologists from Penn excavated a funeral site in central Turkey that they believed to be the tomb of King Midas or his father, Gordius. It dated to at least 700 B.C. A key feature in the burial chamber was the largest set of drinking vessels found from the Iron Age. They were remarkably well preserved. Researchers collected samples of food and beverage residue in the barrels, but they didn't have techniques to make use of them. So the samples sat in their original paper bags for about 40 years until McGovern decoded what people were drinking in antiquity.

McGovern extracted the organic material from the residues using chloroform and methanol. In later research of other ancient brews, pottery vessels and shards were analyzed using infrared spectroscopy, gas and liquid chromatography, mass spectrometry and other instruments searching for clues of the most likely ingredients.

It turns out the Mesopotamians were drinking brews that combined barley beer, grape wine and honey mead. During a dinner honoring beer authority Michael Jackson, McGovern announced a competition among craft brewers to replicate the ancient brew. Dogfish Head Brewery, a highly regarded Delaware producer, triumphed with its creation of Midas Touch. Since then, McGovern and Dogfish Head have collaborated on eight ancient beers based on research. The oldest, Chateau Jiahu, was a 9,000-year-old Chinese brew of rice, honey and fruit. One of the most recent, released in 2013, is Kvasir, developed with samples from a 3,500-year-old Danish drinking vessel made of birch bark found in the tomb of what McGovern thinks was an upper-class dancer or priestess. The ingredients include wheat, myrica gale (a fragrant shrub), yarrow, birch syrup, honey, lingonberries and cranberries. "With the Kvasir, we've taken microorganisms from Belgium," McGovern says. "We'd like to get microorganisms from farther north, too. That can add a lot of flavors and aromas."

How close are the ales to what the ancients drank?

"You don't know the percentage of ingredients," McGovern says. "You don't know if it's a single fermentation or multiple fermentations. In only one case were we able to find yeast, a precursor to *Saccharomyces* we found in an Egyptian date grove. There's a lot you don't know, but if you can take the basic ingredients and come up with something that draws upon local microorganisms, techniques that were used such as fermenting in pottery, or bronze, you can play with the variables and see what you come up with."

BEER'S WILD FUTURE?

For Yakobson, it's still all about the variables and the mysteries of the unknown, and although he's looking forward, he knows this may still be the prehistory of craft brewing.

He hopes that in time, "wilds" will emerge as a third beer category distinct from ales and lagers.

"There's still a lot we don't know," he says. "The scientific literature is on *Saccharomyces*. It gives you temperatures, oxygenation ratios, but everything assumes it's domesticated yeast. But Bretts have an enzyme other brewer's yeast doesn't, and they can draw out purer expressions of hops and give a much fuller continuum of flavors. The mechanisms have been studied only in relatively small ways. There's not a lot of research into bacteria, either."

In the course of his seminar, he has moved on through a series of other bottles, including the grapefruit-colored Vieille and the 100 percent Brett style, Hop Savant. He still has the attention of the group, for whom the seminar is the warmup. In the evening, there will be a 10-course pairing dinner.

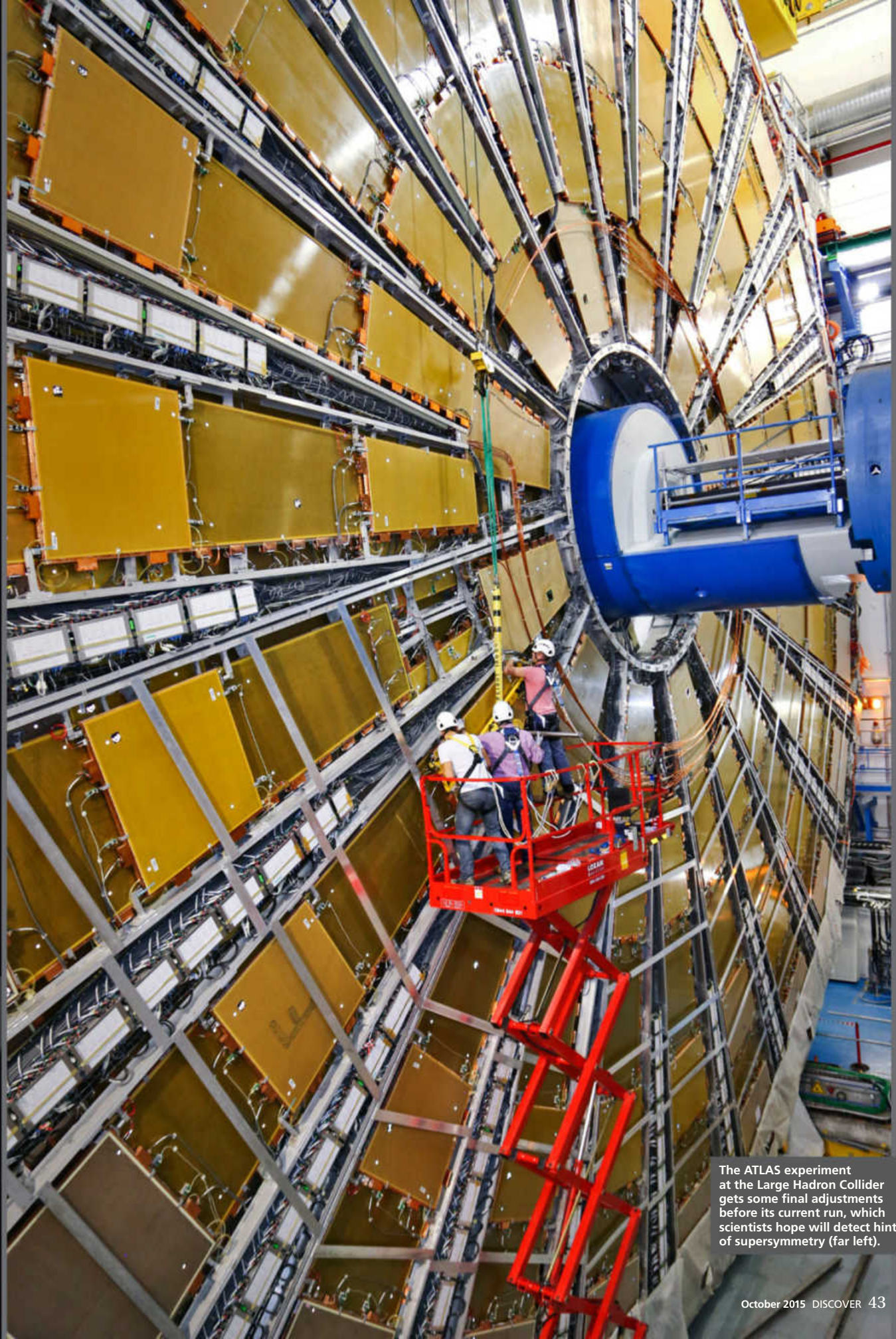
Like a wine enthusiast describes a pinot grigio as citrusy and crisp with peach undertones, Yakobson hopes people will describe beer in more distinct and complimentary ways. "I want to get to the point where we can talk about complex beers with words like *dank* and *garlic* and *orange marmalade.*" D

Todd Pitock *is a double winner of the 2015 American Society of Journalists and Authors award. His work has appeared in* The Atlantic, The New York Times *and others. But he never drinks beer while writing.*

THE "GOD PARTICLE" WAS JUST THE BEGINNING. THE LARGE HADRON COLLIDER AND OTHER ACCELERATORS ARE POISED TO ANSWER QUESTIONS ABOUT THE VERY FABRIC OF THE COSMOS.

Beyond the Higgs Boson

BY TIM FOLGER



THIS PAGE: CERN. OPPOSITE: CLAUDIA MARCELLONI DE OLIVEIRA/CERN

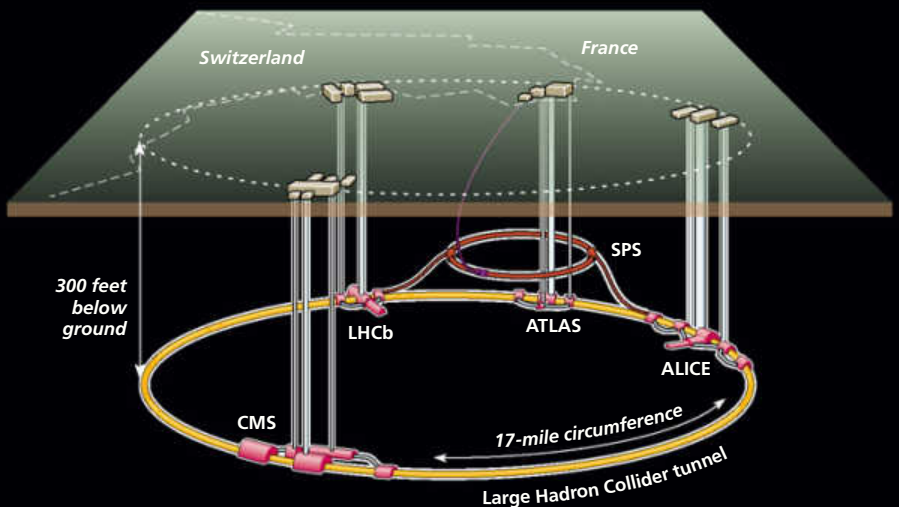
The ATLAS experiment at the Large Hadron Collider gets some final adjustments before its current run, which scientists hope will detect hints of supersymmetry (far left).

On the outskirts of Geneva, Switzerland, some 300 feet underground, is the biggest, most complicated machine ever built. With about 1,200 giant superconducting magnets, multiple-ton detectors, a worldwide computing grid and a staff of thousands, the Large Hadron Collider is an international undertaking beyond the means of any single nation. The project's mission: to see what happens when protons collide at 99.99999 percent of the speed of light in a 17-mile-long circular tunnel.

The LHC started operating in 2008, yet for some physicists it only recently began to live up to its name. "I called it the *Little Hadron Collider*," says Maria Spiropulu, an experimental physicist at the California Institute of Technology, "because during its first run, it only operated at half-energy." That changed in April when the accelerator fired up again after a two-year shutdown dedicated to nearly doubling the energy of its proton beams. Now physicists are anticipating a new era of discoveries from a machine that will dominate experimental particle physics for at least another two decades.

FOUR MAIN EXPERIMENTS

The LHC, on the French-Swiss border, studies what happens when particles emerge from the Super Proton Synchrotron (SPS) and collide at extremely high energies.



The detectors

CMS: Compact Muon Solenoid
Searches for dark matter particles and extra dimensions.

LHCb: LHC Beauty
Studies antimatter and its relationship with matter.

ATLAS: A Toroidal LHC ApparatuS
Like the CMS, it looks for a wide variety of particles.

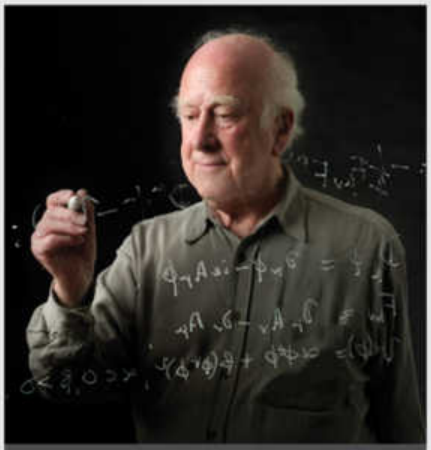
ALICE: A Large Ion Collider Experiment
Examines a rare state of matter that existed just after the Big Bang.

PART 1: The Greatest Machine of All Time

Even before its upgrade, the LHC managed to shake up the physics world. On July 4, 2012, seven months before the machine's hiatus, physicists announced they had discovered the particle that the $4.9 billion accelerator had been hunting: the Higgs boson. The particle's existence was first predicted 50 years ago by several physicists working independently, including Peter Higgs at the University of Edinburgh, as a solution to what had been one of the most vexing mysteries in physics: How do particles acquire mass?

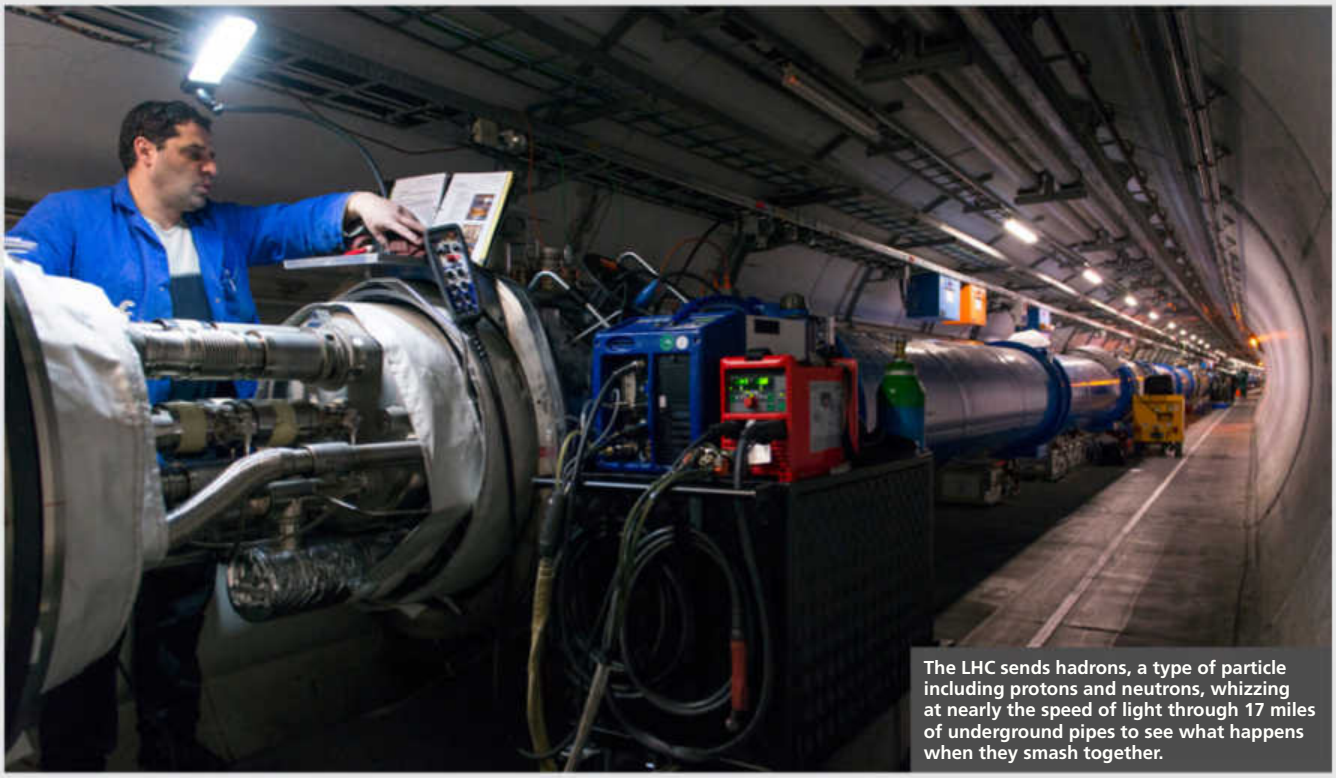
For those of us who aren't physicists, the question barely seems worth asking. Isn't mass simply a given, a basic feature of matter? No, it turns out. Some properties of particles — the negative electric charge on an electron or the positive charge on a proton, for example — *are* intrinsic to the particle itself. But not mass.

Mass varies depending on how fast particles move; protons zipping along at close to the speed of light, like those in the LHC, weigh more than protons at rest. And all the fundamental particles in nature have a seemingly random assortment of masses. Why are protons 2,000 times



Peter Higgs shares a Nobel Prize for proposing that his namesake particle and field explain how matter gains mass.

LEFT: JAY SMITH. RIGHT: CLAUDIA MARCELLONI DE OLIVEIRA/CERN



The LHC sends hadrons, a type of particle including protons and neutrons, whizzing at nearly the speed of light through 17 miles of underground pipes to see what happens when they smash together.

heavier than electrons, yet their charges are simply equal and opposite? Why do photons — particles of light — have no mass at all?

Higgs and company proposed a solution. The universe, they said, is filled with an invisible field, now called the Higgs field, that interacts with all particles via one very special particle: the Higgs boson. Particles that we perceive as being heavy interact strongly with the Higgs field; lighter particles interact more weakly. The discovery of the Higgs boson netted a Nobel Prize in 2013 for Higgs, who is now 86, and François Englert, 82, a physicist at the Free University of Brussels.

STANDARD PRACTICES

With the discovery of the Higgs boson, physicists found the last missing piece of the Standard Model, an overarching theory that describes the universe in terms of a handful of particles and four fundamental forces. "Pretty much everything is explained by the Standard Model," says Hitoshi Murayama, a theoretical physicist at the University of California, Berkeley. "It's an incredible success, and we physicists can boast about it."

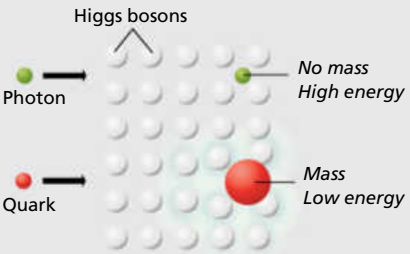
Despite their pride in the theory, Murayama and other physicists can hardly wait to punch it full of holes — their field advances only by tearing down the old and replacing it with something new and even more all-encompassing. The LHC itself was conceived as a Standard Model destroyer.

So far, the Standard Model remains practically impregnable. Its predictions continue to match experiments with uncanny precision. Physicists have never found any solid experimental data that contradict the Standard Model, and that's a problem because they know it can't be the final word on the nature of the physical universe. "We see some hints that there must be something beyond it," says Murayama, "but we don't know exactly what to make of these hints yet."

One of the most obvious hints of physics beyond the Standard Model is the overwhelming evidence for the existence of dark matter in the cosmos. Unlike all other forms of matter, it doesn't interact with light, and astronomers don't know what it's made of. Dark matter betrays its presence mainly by the gravitational influence it exerts on the motions of galaxies.

Observations indicate that more than 80 percent of all the matter in the universe consists of this unknown stuff. The light-emitting objects that have preoccupied astronomers for ages — all the countless stars and galaxies — are

THE HIGGS FIELD



According to the Standard Model, particles attain mass by interacting with an invisible "Higgs field" via the Higgs boson.

TOP: MAXIMILIEN BRICE/CERN. BOTTOM: DESIGNUA/SHUTTERSTOCK AND ALISON MACKEY/DISCOVER

Dark matter, shaded blue in these Hubble telescope photos of galaxy clusters, invisibly litters the entire universe.

NASA, ESA, D. HARVEY (ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, SWITZERLAND; UNIVERSITY OF EDINBURGH, UK), R. MASSEY (DURHAM UNIVERSITY, UK), T. KITCHING (UNIVERSITY COLLEGE LONDON, UK), AND A. TAYLOR AND E. TITTLEY (UNIVERSITY OF EDINBURGH, UK)

apparently exceptions to the rule of cosmic invisibility.

Many physicists are betting that dark matter particles will turn up in the debris created by the upgraded LHC's more energetic proton collisions, and searching for them will be one of the project's prime tasks in the years ahead. But since no one really knows what dark matter is, success is far from certain even from a machine as powerful as the LHC — which, in effect, re-creates the energetic environment of the first thousandth of a billionth of a second of the universe's existence.

"There's no guarantee," says John Ellis, a theoretical physicist at King's College London. "We just have to crank up the energy as high as we can and make as many collisions as we can and see what we find."

PART 2: The Fate of the Universe and Other Quantum Quandaries

Perhaps even more significant than what the LHC found during its first five years of operation was what it didn't find: evidence for physics beyond the Standard Model. Physicists had what they thought would be an ideal extension of the Standard Model, a theory honed over more than 40 years, ready and waiting to be confirmed at the LHC.

Supersymmetry — or SUSY, as physicists call it — predicts that every particle known to physics has a heavier, "super" partner: For every electron, there's a *selectron*; for every quark, a *squark*. SUSY effectively doubles the number of particles in the universe. And although the Higgs field explains *how* particles acquire mass, SUSY explains *why* protons, electrons and other conventional particles have such disparate masses. It also provides a solution to the problem of dark matter in the form of a particle called the neutralino, which, if it exists, would be 100 times heavier than a proton and would hardly interact with normal matter at all — a billion or so could be passing through our bodies every second.

It's an elegant hypothesis, but for now it is only that. For a generation of physicists who have invested entire careers working on supersymmetry, the first low-energy run of the LHC was a huge disappointment. None of the expected superparticles turned up in the accelerator. There's no evidence that supersymmetry exists anywhere other than in the minds of theorists.

At least not yet. "It's reasonable to say that we're worried," says Joseph Lykken, a theoretical physicist and deputy director of Fermi National Accelerator Laboratory in Illinois. "But it's certainly not the case that SUSY is dead. It's a good example of how the game is supposed to work. If we could figure it all out on the blackboard, we wouldn't need to build a $5 billion accelerator."

The challenge for SUSY advocates — a camp that includes nearly all theoretical particle physicists looking beyond the Standard Model — is that the most mathematically straightforward versions of the theory predicted that the LHC should already have found a few of the superparticles in the same collisions that produced the Higgs. Since it didn't, theorists have fallen back on more complicated, less "natural" versions of supersymmetry. Hard data now constrain the theorists' imaginations. "We're straitjacketed," says Murayama.

FEELING THE BURN

One such straitjacket is the mass of the Higgs boson detected at the LHC. Physicists typically describe a particle's mass in units of energy, using Einstein's famous equation, $e = mc^2$, which defines the equivalence of mass and energy. The Higgs has a mass energy of 126 billion electron volts. On a human scale, that's a tiny number — less than a billionth of a billionth of a gram. But on a microscopic scale, it's huge — heavier than some entire molecules. Unfortunately for the long-term fate of the universe, however, it's not quite heavy enough.

When theorists plug that 126 billion electron volt mass (along with another known mass, that of the heaviest observed particle, called the top quark) into the equations that describe the Higgs field, they get a disturbing result: a barely stable field. These equations would indicate that, at some point in the very distant future, a quantum fluctuation could spontaneously "burp" a high-energy bubble into existence that would spread across the entire universe at the speed of light, destroying everything

in its path. Simple hydrogen atoms would be the only form of matter left in that bleak cosmos.

"You can do a calculation of how long [the cosmic burp] will take to happen, and it's something like 10^{100} years," says Spiropulu. "In my opinion, that tells you something is wrong. It probably means that you have some other physics effect going on that you haven't accounted for."

The weird doomsday prediction *could* be a sign that supersymmetry is correct. If the same Higgs-field calculation is done taking SUSY into account, no cosmic *Götterdämmerung* results. Supersymmetry predicts there might be as many as five different Higgs bosons, all with different masses, in which case physicists at the LHC might only have discovered the lightest one. The only way to find out will be to produce many more Higgs bosons over the next few years to see if any of them might be super-Higgses.

"What we're expecting is that this next run of the LHC will give us 10 times as many Higgs bosons as we've had so far," says Ellis. "So there's a lot riding on precision measurements to see if their properties are what is predicted by supersymmetry or not."

PART 3: The Next Big Accelerator

In a display case at the Lawrence Hall of Science in the foothills above the UC Berkeley campus rests the pint-size progenitor of the Large Hadron Collider. Built of wire and sealing wax in 1930 by a 29-year-old physicist named Ernest Lawrence, the cyclotron, as it came to be called, had an accelerating chamber measuring just 4 inches across — about the size of a saucer. With it, Lawrence kicked protons to energies of 80,000 electron volts. Its price tag? Twenty-five dollars. The invention earned Lawrence — who was nicknamed "the Atom Smasher" — the 1939 Nobel Prize in Physics.

Atom-smashing costs have risen considerably; so have the sizes of the machines that do the smashing. The LHC can reach energies nearly 100 million times higher than Lawrence's small device, but it took decades and billions of dollars to build, and it required the expertise of thousands of physicists and engineers. As for scale, its circular tunnel spans almost 5½ miles across — about 84,000 times that of the ancestral cyclotron. The giant machine is expected to run until at least 2035, but physicists are already planning for the accelerator that they hope will succeed it.

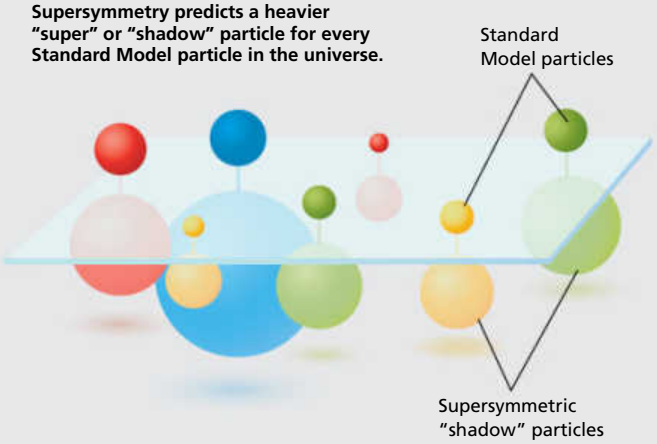
Ernest Lawrence works on a 37.5-inch cyclotron, a great-granddaddy of the LHC.

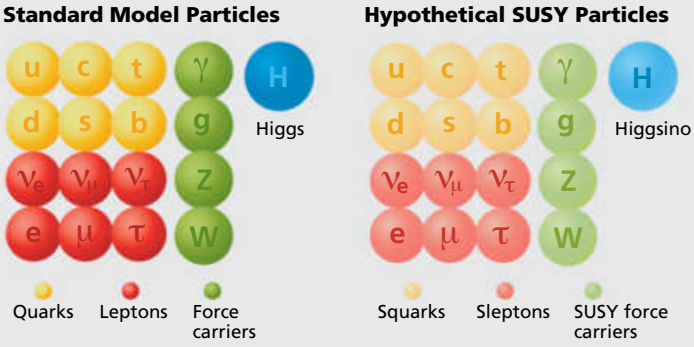
"Because of the time scales involved in these projects, you can't afford to make a mistake," says Lyn Evans, director of the Linear Collider Collaboration, a group of some 2,000 physicists and engineers who are coordinating the efforts to develop the next generation of particle accelerator. "Physicists started planning for the LHC in the early 1980s. It was approved in 1994, and it was 2010 before it was really operating. So the time scales and the decision-making process are really long."

Unlike the LHC, the next big accelerator probably won't be circular. While a circular machine has many

SUPERSYMMETRY AND PARTICLE PAIRS

Supersymmetry predicts a heavier "super" or "shadow" particle for every Standard Model particle in the universe.





Supersymmetry remains just an interesting, if mathematically elegant, hypothesis right now. It would explain why particles have the masses they do and shed light on dark matter. Many versions of the theory suggest the LHC's current experiments will be energetic enough to produce the heavier supersymmetric particles — if they exist.

TOP: LAWRENCE BERKELEY NATIONAL LABORATORY; BOTTOM FROM LEFT: DESIGNUA/SHUTTERSTOCK; ALISON MACKEY/DISCOVER

advantages — protons can be whipped through the LHC's tunnel multiple times, getting an energy boost on every circuit, and the beams can be crossed repeatedly at many points, creating more collisions — there are trade-offs. The LHC needs enormous magnets to force particles to travel in circles. And when particles accelerate along circular paths, they radiate away energy, so less is available for collisions.

LINEAR PROGRESSION

The leading candidate for succession is a project called the International Linear Collider. The ILC would hurl electrons and their antimatter counterparts, positrons, from opposite ends of a straight, 19-mile-long tunnel, generating collisions at the machine's center. By using electron and positron beams instead of heavier protons, the ILC will allow physicists to probe particle properties with much greater precision than they can at the LHC.

"The LHC is a like a collider of cherry pies," says Berkeley's Murayama. "Cherry pies are easy to throw, and they smash together rather easily, but they produce a huge splash, and all the goo comes out of the pie." In the case of the LHC's collisions, the "goo" consists of the protons' components — quarks and gluons. The sheer messiness of proton-proton collisions makes it difficult to detect new particles, or to make accurate measurements of known particles.

Electrons and positrons, on the other hand, don't have any components, so the collisions are cleaner. At the LHC, maybe one in a billion proton-proton collisions yields a Higgs boson. Physicists estimate that a Higgs should pop up roughly every hundred electron-positron collisions at the ILC. The challenge then will be aiming the electron beams accurately enough to ensure enough collisions occur.

"In circular colliders, you have collisions happening many times as the beam circulates inside the ring," says Murayama. "But a linear collider gives you only one shot, and to get decent data, you have to squeeze the beam down to an incredibly small size so the probability of a collision between an electron and positron becomes high."

The ILC's collision point will be will be less than 10 nanometers — about a hundred atoms wide. "You have to operate these tiny objects coming at the speed of light and make sure they meet! I'm still surprised that people think they can do this," says Murayama.

But the project's supporters say the only thing the ILC needs now is funding, as well as a country willing to host the project — Japan is currently the front-runner. "The ILC is shovel-ready," says consortium director Evans. Like the LHC, it will take more than a decade to build. Cost estimates range from $10 billion to $25 billion.

THE NEXT FIX

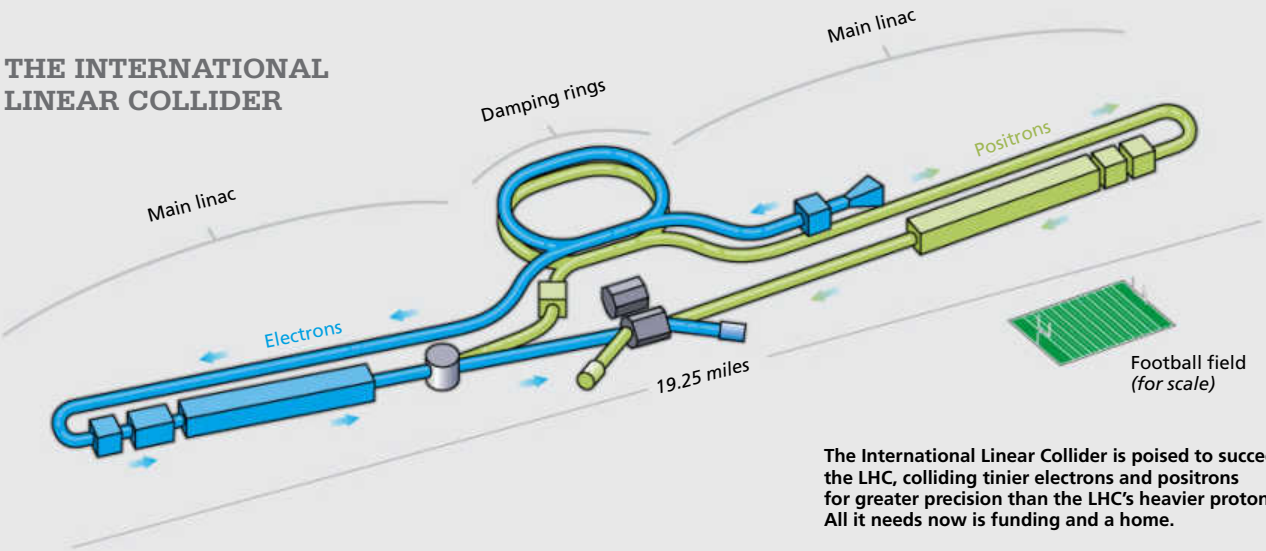
The LHC is giving physicists their first look at an entirely new high-energy realm, but so far, aside from the Higgs boson, nothing new has turned up.

"For me, the next run of the LHC will be very important," says Evans. "If SUSY is not found, then the justification for a linear collider will be even stronger." It's possible, he says, that the LHC may fail to find evidence for new physics — the energies required may simply lie beyond the reach of any machine we could conceivably build.

Even so, exacting measurements of the Higgs boson at the ILC might still allow physicists to tease out fine differences between the predictions of SUSY — or perhaps some other theory, should SUSY fizzle — and those of the Standard Model.

"We would be able to measure the properties of the Higgs boson with extreme precision," says Evans, "and try to crack the Standard Model in that way."

THE INTERNATIONAL LINEAR COLLIDER



The International Linear Collider is poised to succeed the LHC, colliding tinier electrons and positrons for greater precision than the LHC's heavier protons. All it needs now is funding and a home.

JAY SMITH AFTER INTERNATIONAL LINEAR COLLIDER GLOBAL DESIGN EFFORT

Part 4: The Last of the Big Accelerators

As physicists continue their efforts to unravel the warp and woof of the physical world, they will need increasingly powerful machines. A generation from now, their greatest challenge may not come in the form of some unknowable mystery of nature, but rather from the inability — or unwillingness — of society to fund ever larger and more expensive accelerators.

"Unless we do something dramatically different, we will reach the end of the line, whether that's 10 years from now, 20, or 30," says Wim Leemans, director of accelerator technology and applied physics at Lawrence Berkeley National Laboratory. "The machines will become too large and too costly to build unless we come up with radically new technology."

Leemans has been working on a fundamentally new type of accelerator that may allow physicists to scale back the size of their particle-smashing behemoths without sacrificing power.

His device relies on extremely short, powerful bursts of laser beams. The laser fires quadrillion-watt pulses into a thin, 9-centimeter-long sapphire tube filled with hydrogen gas. As the laser shoots through the gas, it strips electrons away from the hydrogen atoms. The laser acts sort of like a motorboat, dragging those particles in its wake, says Leemans.

He and his colleagues have managed to accelerate electrons to about 4 billion electron volts in a device that is less than a meter long (not including the room-filling laser).

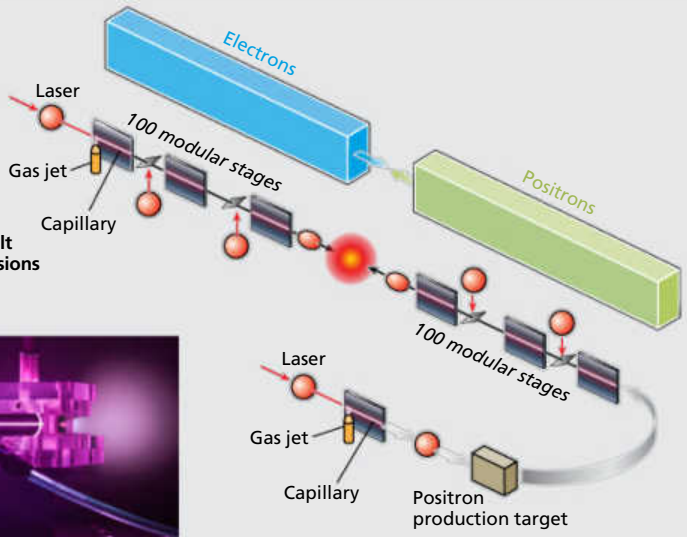
"We're aiming at 10 billion electron volts," says Leemans. "We think we can do that in half a meter." That would put his tabletop device nearly on a level with the Stanford Linear Accelerator, which pushes particles to 50 billion electron volts in a 2-mile-long tunnel.

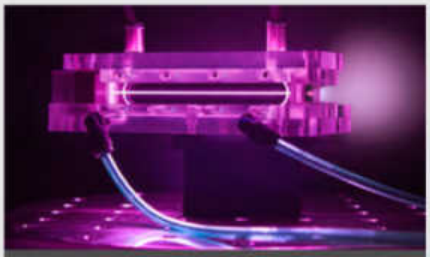
Still, Leemans says he has a long way to go before matching the trillion electron-volt energies of a machine like the LHC. Scaling up his system will require coordinating the firing of multiple lasers with nearly quadrillionth-of-a-second timing.

If he succeeds, how small could a laser-driven accelerator be that could perform at the frontiers of physics? "That's a difficult question," he says. "We don't know the precise answer. Our straw-man designs say we should be able to build a linear accelerator well under a kilometer long."

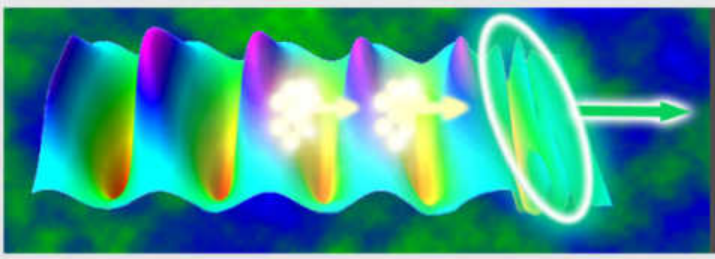
LASER-PLASMA ACCELERATOR

By shooting lasers through tiny gas tubes, physicists could accelerate electrons and positrons continuously. Stringing together multiple "modular stages" could result in supercollider-worthy collisions over a much smaller area.





Compact accelerators can already produce tremendously energetic particles (4.25 billion electron volts) over just about 3.5 inches.



A laser pulse traveling through hydrogen, shown as the ellipse moving toward the right, accelerates free electrons (center) in its wake.

THE BIG QUESTIONS

Such a machine is still decades away. But something like it will be essential if advances in particle physics are to continue after the LHC shuts down in 2035. By then, perhaps, physicists will have solved the mysteries of dark matter; maybe supersymmetry will be on firm footing. Or maybe the Standard Model will continue to reign supreme, and physicists will still be looking for their theory of everything.

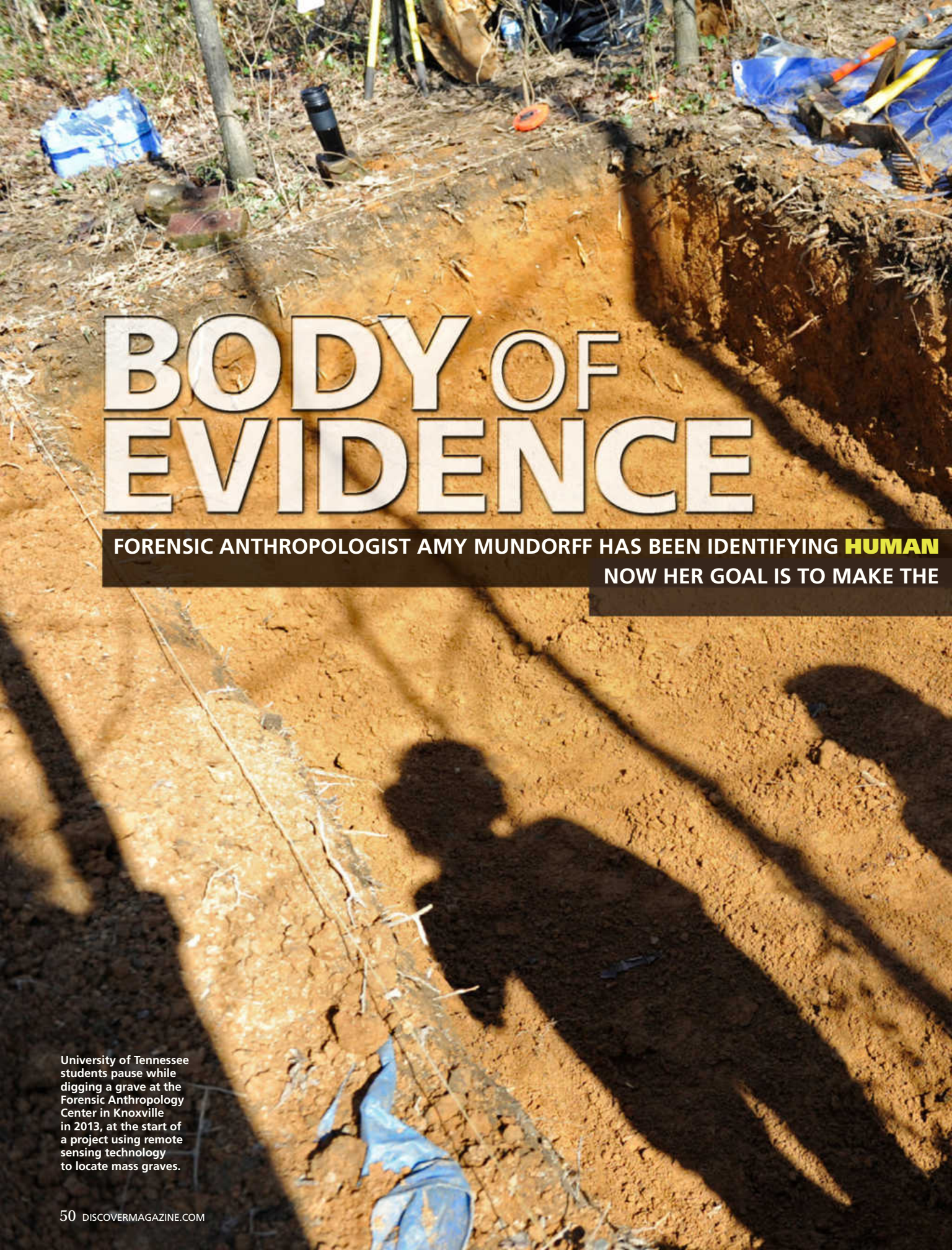
"We've come a long way in understanding the fundamental nature of the universe," says Joseph Incandela, a physicist at the University of California, Santa Barbara, and the leader of one of the teams that discovered the Higgs boson. "Heck, this whole idea, if you think about it, goes back 2,600 years. So we, the human race, have to be patient. The breakthroughs have been so quick and so stunning in the last century and a half or so that we've become kind of spoiled. It could be that we have to leave some things for future generations." D

Tim Folger *is a contributing editor to* Discover *and series editor of* The Best American Science and Nature Writing *series, an annual anthology. He lives in New Mexico.*

FROM TOP: JAY SMITH AFTER LAWRENCE BERKELEY NATIONAL LABORATORY; ROY KALTSCHMIDT/LAWRENCE BERKELEY NATIONAL LABORATORY; LAWRENCE BERKELEY NATIONAL LABORATORY

BODY OF EVIDENCE

FORENSIC ANTHROPOLOGIST AMY MUNDORFF HAS BEEN IDENTIFYING HUMAN
NOW HER GOAL IS TO MAKE THE



University of Tennessee students pause while digging a grave at the Forensic Anthropology Center in Knoxville in 2013, at the start of a project using remote sensing technology to locate mass graves.

REMAINS FOR YEARS.
SEARCH FOR THE MISSING **SAFER** AND **MORE SUCCESSFUL.** BY **HANNAH HOAG**

PHOTOS BY **AMY SMOTHERMAN BURGESS/KNOXVILLE NEWS SENTINEL/ZUMA**

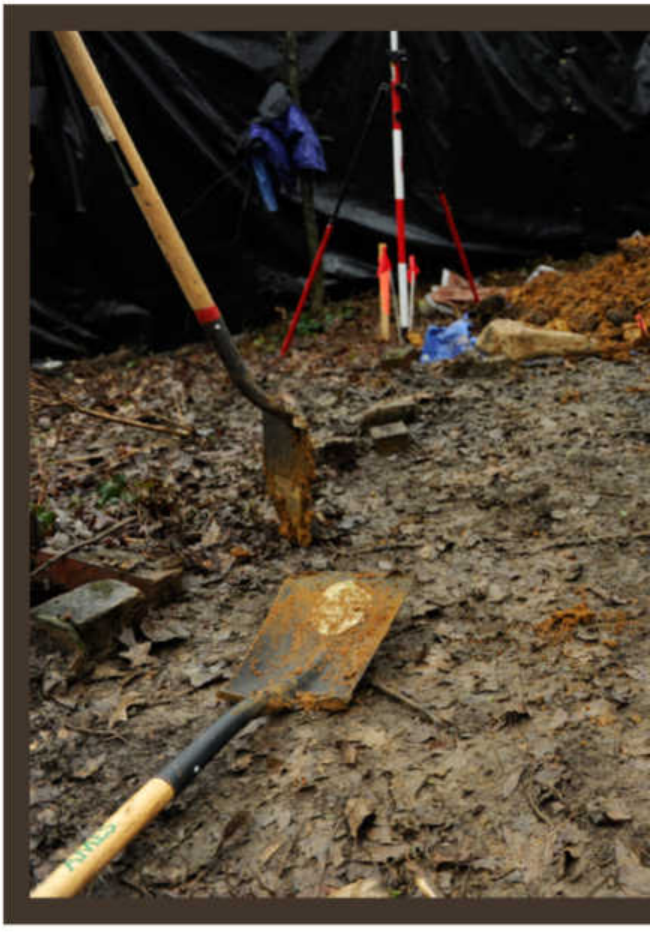
ONE MORNING IN JULY 2005, Amy Mundorff rode into the Bosnian countryside, tagging along with a team from the International Commission on Missing Persons. The roads wound past forests, farmland and villages. The group stopped near a field in a hilly area on the outskirts of a village to meet an informant. From the gestures and the translator's comments, Mundorff understood that the ground beneath the field might hold bodies.

The war in Bosnia-Herzegovina had ended 10 years earlier, but thousands of people remained missing, many presumed buried in hidden graves scattered across the country. Mundorff, a forensic anthropologist, wanted to learn how the team excavated and exhumed graves, and then sorted and identified co-mingled human remains — her area of expertise.

Backhoes scraped away the topsoil, peeling back the earth inches at a time. "They just dug and dug and dug," recalls Mundorff. Once in a while, the machinery operators would stop and call over an investigator. "It was never anything human. There were roots, animals bones, rocks … but there were no graves," says Mundorff. By the end of the day, the entire hillside had been dug up, and the team found nothing.

Witness and survivor testimonies remain the most reliable way to locate hidden graves, but the approach is not foolproof. Many of the conflicts under investigation occurred years ago. Elderly witnesses may have fading memories that offer incomplete or incorrect accounts of atrocities. Sometimes the geography of a place changes. Roads get rerouted, forests are cleared, and the edges of villages expand.

Mundorff knew from her own searches for buried murder victims in the United States that investigators often fail to locate hidden graves, but she didn't expect it to be so difficult in Bosnia-Herzegovina: The country is smaller than Louisiana, and the whereabouts of 8,000 people remain unknown.



Mundorff didn't expect it to be so difficult to locate hidden graves in Bosnia-Herzegovina. It's smaller than Louisiana, and 8,000 people are missing.

"Even if we didn't find that one grave, I thought we would find something because … where are they?" says Mundorff. She was disappointed and frustrated. "I thought, 'God, there has to be something better out there.'"

A CALLING UNCOVERED

Growing up in Connecticut, Mundorff, now 46, was always captivated by the stories held in long-buried objects. Her grandmother, who studied under pioneering anthropologist Franz Boas at Columbia University, also inspired her. But it was during a visit to Israel, where Mundorff brushed aside dirt to reveal a mosaic floor of a Byzantine temple, that she got hooked on unearthing history.

As a student at Syracuse University, she spent three summers in Jamaica excavating the slave quarters of an old sugar cane plantation, including bodies buried beneath the buildings. "I was fascinated by the stories skeletons could tell. My first skeleton had gallstones, and I wondered if he even knew," she says.

She worked about five years as an archaeologist in Hawaii and California, jumping from job to job and living out of a duffle bag in hotels and campgrounds. Eventually, her love for the human skeleton drew her into the graduate program in anthropology at California State University in Chico. In 1999 she landed a job as the first and only full-time forensic anthropologist in the Office of the Chief Medical Examiner (OCME) in New York City.

In New York, Mundorff analyzed decades-old bones dug up by construction crews and worked closely with the New York Police Department to help with exhumations. When heavily decomposed, unrecognizable bodies came into the morgue,

Forensic anthropologist Amy Mundorff measures the depth of a grave as the remote sensing research project gets underway (far left). Grad student Katie Corcoran records gravesite info (above), and Dawnie Steadman, director of the Forensic Anthropology Center, assists in the process (left). Ten human bodies were donated for the multiyear project.

she pieced together biological profiles to provide investigators with an age range or an indication of the person's height. She considered it her dream job.

SURVIVOR STORY

On the morning of Sept. 11, 2001, Mundorff was pulled from a staff meeting and told that American Airlines Flight 11 had just struck the north tower of the World Trade Center. She and seven others were directed to head downtown to gauge the situation so they could establish a temporary morgue.

"I questioned whether we should really be going down there. We didn't know what was going on. We weren't first responders. What if there was a bomb or another explosion?" she recalls thinking. "But I pushed my better judgment aside, and I went. It is the only real regret I have in life." The team members climbed inside two cars and raced 50 blocks downtown. Just before they left their offices, the second plane, United Airlines Flight 175, hit the south tower.

Mundorff was standing on West Street, near the Marriott Hotel, surveying the area amid the debris and chaos when she heard a loud noise and turned around to see the south tower crumbling. She started running. The building's collapse created a seismic wave that had a local magnitude of 2.1. Debris surged toward Mundorff, threw her into the air and knocked her unconscious. "I thought I was going to die," says Mundorff. "After it ended, it was just black."

She came to 10 to 15 seconds later on the other side of the street, at the foot of 1 World Financial Center. She remembers hearing sounds. "All the firemen have alarms on their air tanks that go off if they're down for more than 30 seconds. There were hundreds of those alarms going off," she says. Mundorff had been standing within the tower's kill zone — the pressure wave had stripped the stone facade from the building behind her. A fire engine had flipped over; a steel beam had crushed the car she arrived in. She started yelling, "I'm alive! I'm alive!" She dug herself from the rubble and walked toward the river in search of cleaner air.

Two days later — covered in bruises, with cracked ribs, stitches in her leg, a large bump on her forehead and two black eyes — Mundorff returned to work. The remains of the victims who died in the disaster had begun to arrive at the OCME.

Mundorff worked 12 hours a day, seven days a week to

identify the victims. She sat at a triage table at the head of the mortuary assembly line, sifting human bone fragments from building materials and animal remains, and separating unrelated parts. She was exhausted, but unwilling to step back. "I survived, and they didn't," she says. "It was something I had to do. It was my job. I just did it."

LESSONS LEARNED

After three years and 1,598 victim identifications, Mundorff needed a break from the front lines. She also felt that future mass-fatality managers, whether identifying victims of natural disasters, war crimes or acts of terrorism, could learn from the data collected and methods refined in the World Trade Center Victim Identification Project. In August 2004, Mundorff drove to Vancouver, British Columbia, to pursue a doctorate degree at Simon Fraser University.

In her thesis on identifying human remains in the wake of the World Trade Center disaster, Mundorff argued that anthropologists should participate in excavations of disaster sites to note the precise location of remains and exclude non-human remains, which would make the process faster.

Her analysis also found that smaller bones, such as those in the foot or the kneecap, yielded DNA that could be used for identifications at about the same rate as the femur and other larger bones, which, until then, were considered the best options. In disaster situations, time is short and electricity may be unavailable. Removing smaller bones with disposable scalpels instead of bone saws speeds up sampling, reduces contamination and is less destructive.

As Mundorff worked on her thesis, the futility of the search in Bosnia continued to dog her. She would kick around ideas during weekend rock climbing trips with her husband and friends, including Michael Medler, a fire geographer at Western Washington University in Bellingham. Medler uses remote sensing technologies to document vegetation conditions and predict forest fire risk.

"Climbing is a great way to talk about what you can see down below you," says Medler. "I would yammer on, saying, 'You know, these [graves] ought to leave a mark.'"

Medler uses LIDAR, short for light detection and ranging technology. Strapped to the belly of an airplane or helicopter, a LIDAR device fires millions of laser beams down onto the landscape. Some pulses rebound off the forest canopy, while

Mundorff and her colleagues break ground at the research site, a wooded bluff on the Tennessee River, in February 2013 (left). Graduate student Jake Smith carries a board used to bring one of the 10 donated bodies to the gravesite (above). By November 2014, the only signs of the graves are white marker flags (right).

FAR RIGHT: HANNAH HOAG

"You know," says fire geographer Michael Medler, who uses remote sensing technology to predict forest fire risk, "these [graves] ought to leave a mark."

others slip between the leaves like raindrops and ricochet off the ground. Together, they create a 3-D map. The technique has transformed archaeology, giving scientists the ability to peer through dense vegetation and see long-hidden temples, boulevards, dikes and cityscapes — angular human-made structures that pop out of otherwise natural landscapes.

The potential for using LIDAR to find hidden graves appealed to Mundorff because it's an aerial instrument. Human rights investigators could use it when it is still too dangerous to send personnel into a post-conflict area.

PLANTING EVIDENCE

By 2007 Medler and Mundorff had resolved to test whether hidden graves could be found remotely, but they needed funding, and Mundorff was still a student. So the idea languished.

After receiving her Ph.D. in 2009, Mundorff took a faculty position at the University of Tennessee in Knoxville. Since the mid-1980s, the university has run one of the few outdoor facilities where scientists bury human bodies to study how they decompose under a variety of conditions. For Mundorff, the move was one step closer to testing whether LIDAR and other remote sensing technologies could be used to find unmarked graves.

Other forensic studies have buried cows or pigs, but Mundorff believed it was important to use human bodies to test the LIDAR idea. Because different species may leave distinct chemical signatures in the soil that could in turn affect how vegetation grew at the site, it only made sense to test the technology on humans.

Mundorff also wanted untouched soil, which the Knoxville site lacked after decades of research burials. She would have to wait more than two years for perimeter fencing to be installed around a new plot of land, recently donated to the university, before she could begin her work.

In the meantime, working with colleagues at Texas State University, Mundorff buried a body on a 5-acre forensic

anthropology facility run by the university south of Austin. She hired a graduate student to monitor the site and how plants responded to buried bodies.

Nitrogen is one of the many chemicals bodies release as they decompose. It's also an essential mineral for plant growth. The change in soil chemistry from extra nitrogen could alter the chemical signature of the plants growing over the grave. As a result, thought Mundorff, those plants might reflect red and infrared light differently enough to be picked up by satellites measuring Earth's vegetation. Although the satellite sensors themselves provide only a few points of data per square meter and might not pick up small graves containing a single body on their own, the data they collected might be useful when combined with additional information from LIDAR.

A year and a half after the burial, the grave was covered with grass. The nitrogen levels in the leaves over the graves skyrocketed to five times greater than those in the leaves over the undisturbed soil. The preliminary data supported Mundorff's hypothesis that buried bodies affected the vegetation growing over them.

TENNESSEE JUNGLE

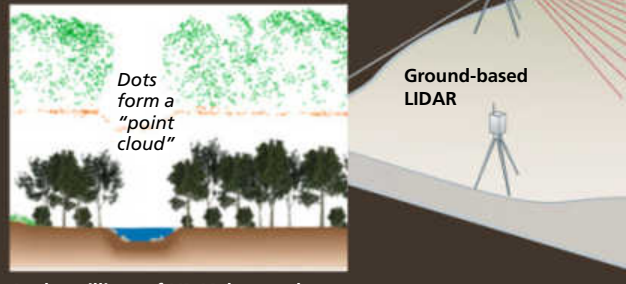
Back in Knoxville, with the fence in place by the closing days of 2012, Mundorff finally got the green light to start her original LIDAR-based research idea. Around Valentine's Day in 2013, Mundorff and a handful of students broke ground at the new site, a wooded bluff on the Tennessee River, opposite downtown Knoxville. Among the students was Katie Corcoran, who recently joined Mundorff's project after working with the Seminole tribe in Florida, using LIDAR

SEARCH AND RECOVERY

Finding hidden graves is often a hit-and-miss process that also can be dangerous in war zones and other areas of instability. Applying different remote sensing technologies could save time, focus resources and protect those searching for the dead.

LIDAR

Light detection and ranging technology (LIDAR) devices, on the ground or secured to a plane or helicopter, fire millions of laser pulses onto the landscape; some bounce off the forest canopy, some off the ground, creating a 3-D map that can reveal subtle changes in topography — including, potentially, graves that are otherwise invisible to the naked eye.



As the millions of LIDAR laser pulses bounce back from different surfaces, each pulse becomes a dot in a "point cloud" that creates a detailed map.

"If each layer of data is an instrument, how do you get them to all play together? You have to turn it into a symphony," says remote sensing expert Devin White.

and historical aerial photos to find archaeological sites.

The team dug into the earth, dark and streaked with tawny-colored clay, with shovels and pickaxes. They carved out four graves for 10 donated bodies. One grave holds the remains of six people; another contains three; and another fits a single body. The fourth grave, dug to the same dimensions as the six-person grave and refilled, would be the control.

For the next several months, Mundorff and Corcoran's team scrutinized the site in almost every way. A photographer documented the graves as they settled. A botanist surveyed the vegetation and mapped its regrowth. A scientist from the nearby Oak Ridge National Laboratory (ORNL) set up thermal cameras to record the temperature of the graves over 24-hour periods while the bodies decomposed. As the seasons shifted, grasses and shrubs reappeared. Mundorff and Corcoran snipped leaves and tucked them into envelopes so they could analyze their chemical composition.

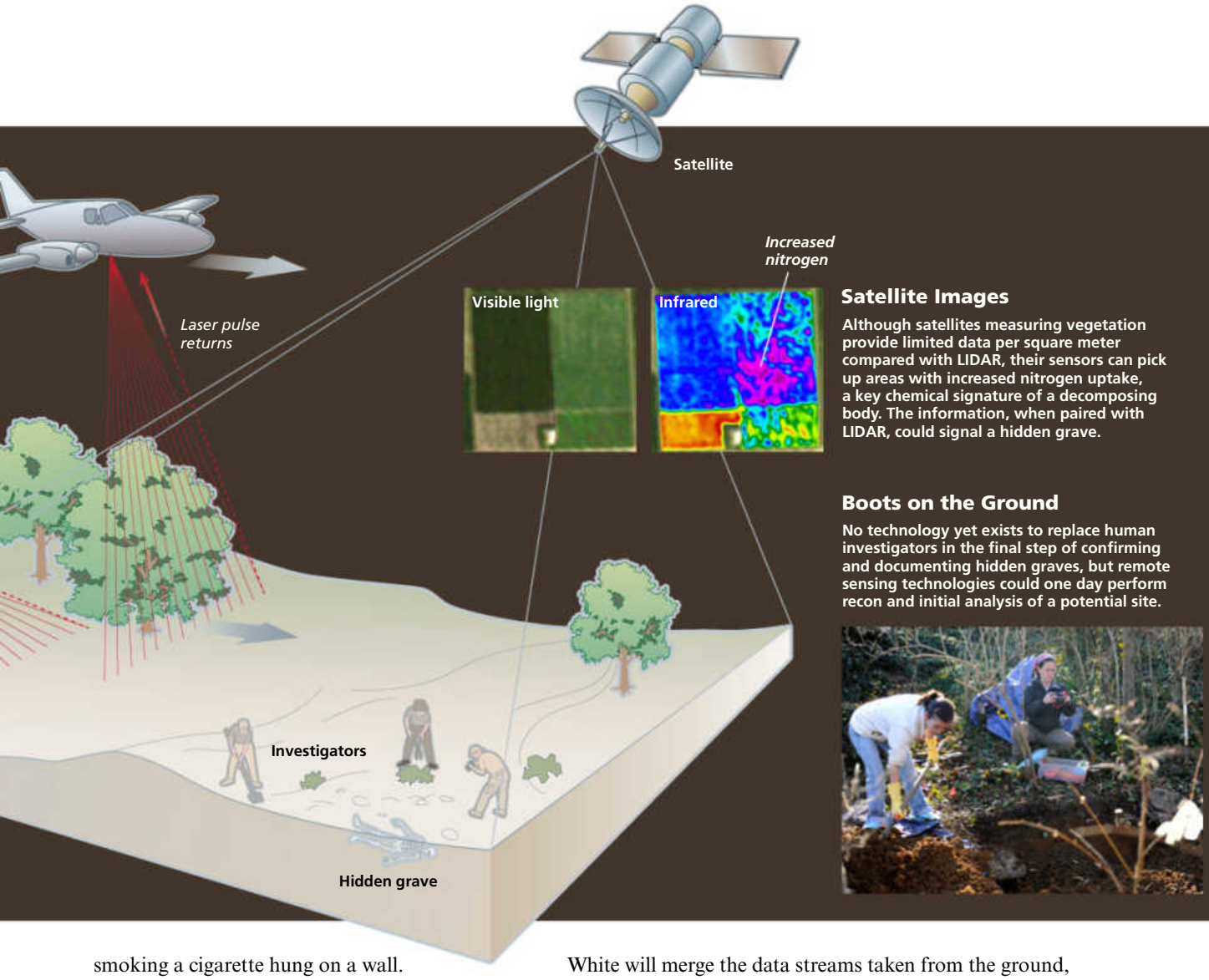
On a crisp November day in 2014, I joined Mundorff and Corcoran at the burial site. Two fences hemmed in the allotment. Mundorff first unlocked an 8-foot-tall chain-link fence topped with razor wire, then an equally high wooden privacy fence, and swung open the gates. Leaf litter from oak and maple trees covered the ground and crunched beneath our boots. Days of rain had left the clay-rich soil soft.

Metal disks stamped with letters and numbers, and nailed to stakes in the ground, identified the graves. Without the markers, they would have been easy to miss.

REMOTE SENSING SYMPHONY

The next day, the three of us met in Mundorff's office for a sneak peek of the next phase of the research. The space is a cinder-block box with high ceilings and fresh blue paint on the walls, buried beneath the university stadium. Bones and other artifacts sat atop bookshelves and tables, and a poster of Van Gogh's painting of a skeleton

FROM LEFT: POINT CLOUD BY NATIONAL ECOLOGICAL OBSERVATORY NETWORK/NATIONAL SCIENCE FOUNDATION/COOPERATIVE SUPPORT AGREEMENT NO. 1029808; ILLUSTRATION BY JAY SMITH; SATELLITE IMAGES BY NASA/GSFC; PHOTO BY AMY SMOTHERMAN BURGESS/KNOXVILLE NEWS SENTINEL/ZUMA



Satellite Images

Although satellites measuring vegetation provide limited data per square meter compared with LIDAR, their sensors can pick up areas with increased nitrogen uptake, a key chemical signature of a decomposing body. The information, when paired with LIDAR, could signal a hidden grave.

Boots on the Ground

No technology yet exists to replace human investigators in the final step of confirming and documenting hidden graves, but remote sensing technologies could one day perform recon and initial analysis of a potential site.

smoking a cigarette hung on a wall.

Corcoran loaded onto her laptop LIDAR images collected before the burial. Eight million points populated the screen in a dense 3-D image called a point cloud, showing streets, buildings and hills. With a few clicks, she zoomed in to the site and stripped away vegetation to reveal the contours of the bare earth.

Corcoran switched to a satellite image also taken before the burial. It looked like a photograph, but it was a composite of several spectral bands, each measuring the reflectance of the surface at different wavelengths of light. She highlighted the vegetation by selecting the infrared band. Knoxville's wooded areas and fields glowed red.

These "before" images provide an important baseline that Corcoran and Mundorff can use to compare against the data they're collecting through spring 2016. They've enlisted the help of Devin White, a remote sensing expert at ORNL who has used airborne and satellite imagery to identify ancient footpaths threading through the Sonoran desert between Arizona and Mexico. White will merge the data streams taken from the ground, air and space, and use it to spot locations of interest. "If each layer is an instrument, how do you get them to all play together and do something more than the sum of their parts?" asks White. "You have to turn it into a symphony."

The week is marked by the arrival of a $200,000 ground-based LIDAR scanner, on loan from the Remote Sensing Center at the Naval Postgraduate School in Monterey, Calif. Although Mundorff's goal is for investigators in the field to use aerial LIDAR, the ground-based unit's data — along with existing aerial and satellite imagery — will help White's computers at ORNL learn what a hidden grave looks like.

Mundorff has faced several challenges during the project and admits there is still a lot of work to do, but she remains hopeful that she can develop techniques that will help find the missing, and potentially bring their killers to justice. She may have stopped doing forensic casework, but she remains devoted to developing tools for those who continue to do the difficult work. "I'm a practitioner at heart," she says. "All my research is about the practice of forensic anthropology." D

Hannah Hoag *is a science journalist and editor based in Toronto.*

THE Woman WITH Knives IN HER Neck

When traditional painkillers fail, is medical marijuana the answer?

BY **DAVID CASARETT**
ILLUSTRATION BY **STUART BRIERS**

There's no such thing as a "typical" medical marijuana patient. The marijuana clinics that I've visited have encompassed a wide swath of society, and the people I've met are living proof of the diversity of this population. Nevertheless, my first thought when I meet Rachel in this particular clinic waiting room is that she doesn't belong here.

Rachel is in her early 40s, blond and wearing a crisply tailored deep-blue suit that looks like it's made of expensive silk. Just for comparison, the guy sitting next to her is a skinny, unshaven lad wearing baggy shorts, a tank top and flip-flops. He looks like he's heading to the beach, while Rachel looks like she's taking a well-earned break from a board meeting. Later I find out she's the co-owner of a large chain of boutiques.

Rachel tells me that her experience with medical marijuana began about a year ago, when she was at the site of a new store. A piece of construction equipment fell on her, fracturing her cervical spine and initially leaving her paralyzed. After a month in the hospital, her spine was stabilized, and she was able to walk again.

But she was far from well because pieces of her spine damaged some of the nerves that emerge from the spinal cord. Those damaged nerves caused unpredictable episodes of sharp pain. Rachel tells me the pain feels like knives are stabbing her neck and shooting down her arms as far as her fingers.

"They hit me when I move the wrong way, but I can't avoid them. They just … happen."

Those attacks were so severe, and so unpredictable, they scared her away from regular exercise. Eventually she avoided walking her corgi, Max, or even doing the dishes because she was afraid that the wrong move would bring on another lightning strike. The drugs her doctors prescribed didn't help much, and opioids like morphine made her feel "drugged." So she turned to marijuana.

Rachel tells me that once she started using it, two things happened. First, as she'd hoped, the bouts of pain became less severe. Then as her pain improved a little, she became less afraid of the next episode. She began to exercise more. She took Max for long walks. And then she started seeing her trainer again for light aerobic workouts. Soon it seemed that the spells of pain became less frequent.

She uses a marijuana-based oil in a vape pen. These devices are like e-cigarettes, except that they deliver tetrahydrocannabinol (THC) and cannabidiol (CBD) instead of nicotine. Rachel tells me she uses her vape pen "all day."

How many times in a typical day?

Rachel thinks carefully. "A dozen."

I'm not sure what my expression reveals, but it causes her to re-evaluate her estimate — though not in the direction I expected.

"Maybe two dozen?"

I'm having trouble imagining the effects of 24 doses of THC, the ingredient in marijuana that produces the "high" feeling for which it's so well known. I'm also wondering how that regimen might affect a daily routine that involves managing a chain of clothing stores. But Rachel seems bemused by my questions.

"Well, we opened two new stores in the last three months. I must be doing something right."

BRAIN BUBBLE WRAP

Is she doing something right? Could the ingredients in marijuana be effective in treating pain? To find out, I track down a researcher who has thought a lot about this question.

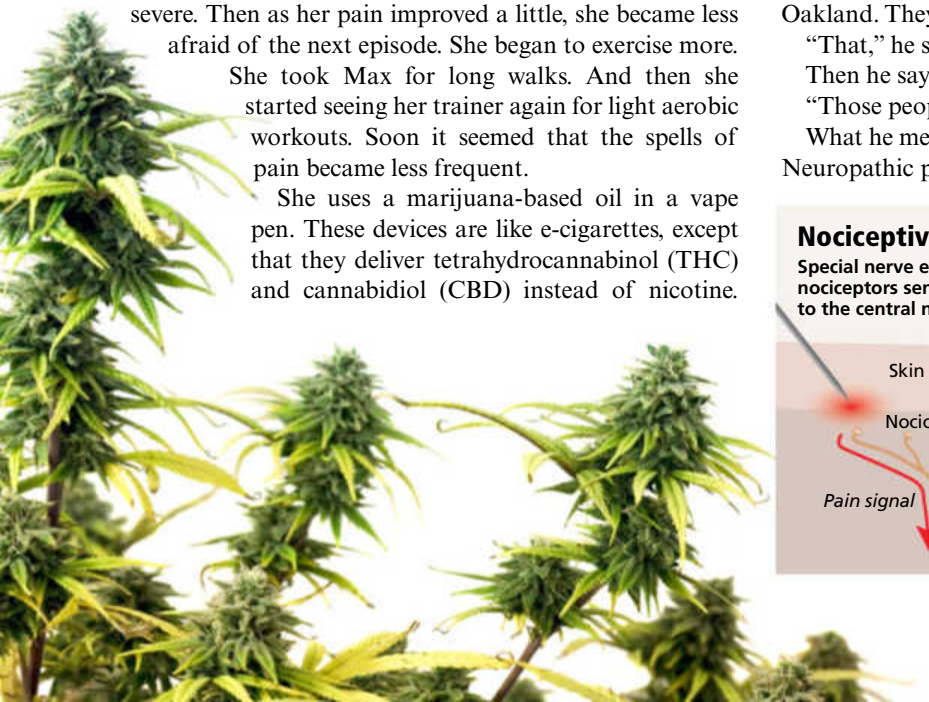
Barth Wilsey is tall and baby-faced with short-cropped hair and the peaceful gravity of a Buddhist monk. He's an anesthesiologist by training, and he's done some of the most interesting research I've seen on marijuana and pain. As I tell him Rachel's story, Wilsey listens patiently, nodding. He tells me it was people like Rachel who led him to study the uses of marijuana in treating pain. Wilsey recalls how, two decades ago, when he was in a pain fellowship in San Francisco, many of his patients got marijuana through a buyer's club in Oakland. They told him it was the only treatment that worked.

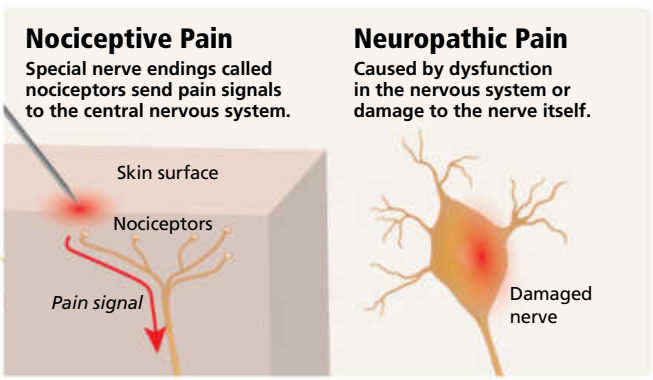
"That," he says, "really grabbed my attention."

Then he says something that grabs my attention.

"Those people all had neuropathic pain, like Rachel did."

What he means is that they had a very specific type of pain. Neuropathic pain isn't caused by a direct injury, like arthritis





LEFT: BOROJOINT/ISTOCK. RIGHT: ALILA MEDICAL MEDIA/SHUTTERSTOCK AND ALISON MACKEY/DISCOVER

Good Meds medical cannabis center in Lakewood, Colo., lines its shelves with medical marijuana. Centers like this one are a resource for patients who need an alternative when typical pain relievers don't work for them.

MATTHEW STAVER/THE WASHINGTON POST/GETTY IMAGES

or a broken bone, that stimulates normal pain nerves — that's nociceptive pain. Instead, neuropathic pain is caused by the nerves themselves.

To understand neuropathic pain, it helps to think about the way that electronic devices like pagers and cell phones work. When I was a resident, two of us had to carry a "code pager" at all times. This was the pager that would go off if someone had a cardiac arrest anywhere in the hospital. Because these devices were so important, they were designed to withstand the apocalypse. To make them especially dependable, these pagers operated on local emergency radio channels that were bulletproof, but filled with static. So every once in a while, a pager would spring to life, emitting an unintelligible squawk and three beeps that would send a confused resident scrambling for the door, until it became apparent that it was just a false alarm.

Is she doing something right? Could the ingredients in marijuana be effective in treating pain?

That's how neuropathic pain happens. An injury to a nerve creates static, but pain nerves don't know how to interpret static any more than those pagers knew how to interpret it. Instead, nerves that carry pain signals interpret static just like they interpret any signal: as pain. Just as those emergency pagers interpreted static as an emergency and let loose a blood-curdling squawk, nerves that carry pain assume that static represents a painful stimulus, and that's what they tell the brain.

Wilsey is particularly interested in Rachel's story because he thinks that if marijuana can treat pain, it's probably most effective against neuropathic pain. And he believes it is effective. In fact, he tells me about several studies that he and others have done, finding that people like Rachel report much better pain relief.

How does marijuana relieve pain? This is where things get interesting, because what Wilsey tells me is not what I expected.

"You've got your glial cells," he says. "They're the predominant cell type in the brain."

I'm confused by this because glial cells are known primarily as the brain's immune cells. They help to scavenge and clean up debris, but they aren't involved in thinking or movement, as neurons are.

So how could glial cells be involved in treating pain? I admit somewhat sheepishly that I've always thought of them as sort of . . .

"Bubble wrap," Wilsey says.

Bubble wrap?

"People used to think of glial cells as the bubble wrap of the brain. They're cells that the important neurons are packed in. Helpful, even essential for immune function. But neurologically inert."

I love this analogy, but I learn that it's not true. Wilsey explains that glial cells aren't just structural, and they're not just immune cells. They may have a big role in pain management. For instance, we know that they have receptors that bind to THC.

He's not sure yet how those glial cells are involved in pain, or how marijuana might act on them to provide pain relief. One theory is that glial cells have some sort of modulating effect on neurons. That is, they might reduce neuronal activity, in much the same way that my fellow residents and I would turn down the volume on those code pagers as far as we could. That adjustment wouldn't eliminate random beeps, but it did

make them less startling. Perhaps those glial cells work through cytokines, which are molecules that coordinate the body's response to inflammation, but we don't really know. Whatever the mechanism, Wilsey is convinced that these glial cells are much more than bubble wrap.

If Wilsey is less interested in neurons than he is in glial cells, he's also less interested in THC than he is in the lesser-known cannabinoid CBD.

THC and CBD have a fascinating relationship that's a little like the one between Don Quixote and Sancho Panza in Cervantes' picaresque tale. The Don was a loopy aristocrat with odd delusions of chivalry and a skewed perception of reality that led him — among other adventures — to imagine that a windmill was a giant against which he was honor-bound to battle. Sancho, on the other hand, was the humble servant and the practical, common-sense squire. He did his best to keep his master on the straight and narrow path, or at least to prevent him from doing too much harm to himself, or to windmills.

THC and CBD have a fascinating relationship that's a little like the one between Don Quixote and Sancho Panza in Cervantes' picaresque tale.

CBD and THC, two of the main active ingredients in marijuana, are gaining the attention of researchers because of their pain-relieving potential.

You can think of THC as the Don Quixote of marijuana's cannabinoids. Its receptors are scattered all over the brain, in the cortex, in the cerebellum and in the reward centers, among other places. So it can make you goofy, confused, high and even paranoid. All those are the quixotic effects of THC, and it's because of those effects that THC is the cannabinoid everyone notices, just as Don Quixote got top billing.

CBD, on the other hand, is more like Sancho Panza. Its most notable characteristic is what it *doesn't* do. Specifically, it doesn't produce any of the psychoactive effects of THC. It doesn't make you feel high or paranoid, and it doesn't make you hallucinate. Like Sancho, CBD does whatever it does quietly, and almost invisibly.

But just as Sancho is as important — in his own way — to the tale as his master is, it's possible that CBD might be more valuable than we thought. And maybe THC isn't as necessary as we'd assumed.

Indeed, Wilsey tells me that this possibility has led him and other researchers to reconsider the way they design clinical trials of medical marijuana for pain. Most trials, he says, focus on marijuana's THC content. CBD content, in contrast, is mostly an afterthought. But Wilsey wants to do trials of marijuana that contains more CBD and less THC, at a ratio of 5-to-1 or higher. He thinks that marijuana with a lot of CBD might lead to greater pain relief and perhaps fewer psychological side effects.

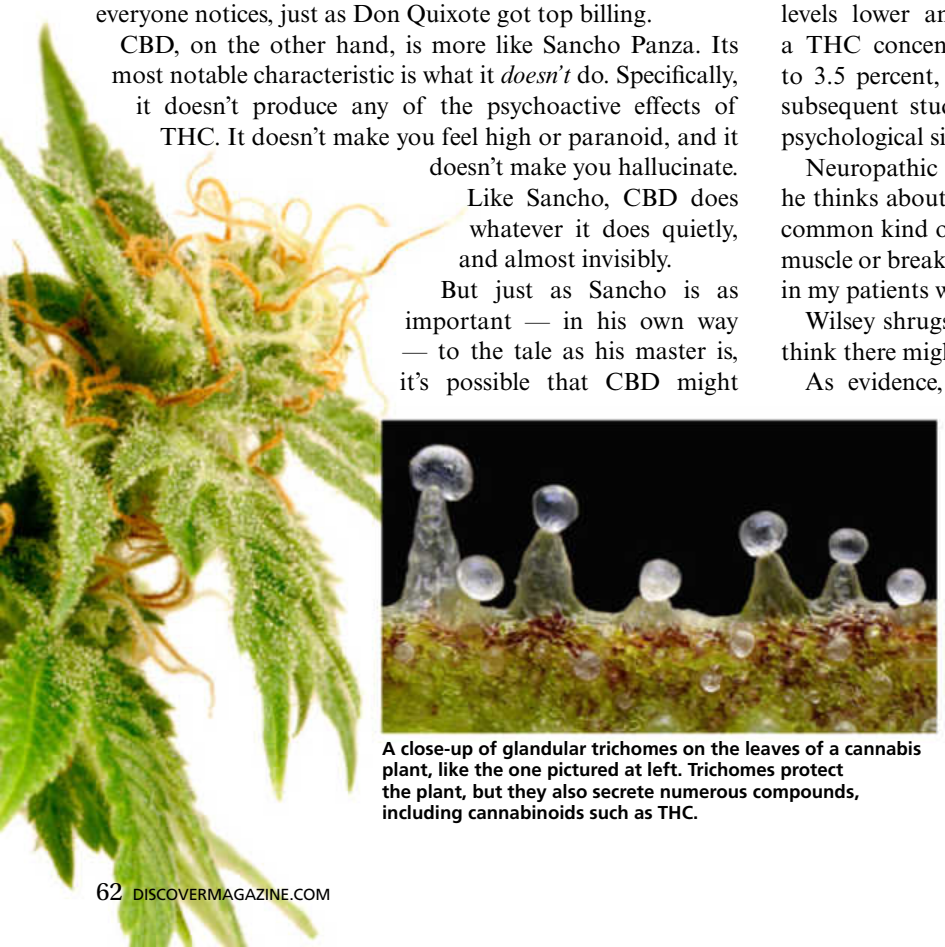
Wilsey tells me that already his studies have pushed THC levels lower and lower. Initially he used marijuana with a THC concentration of 7 percent, then he reduced that to 3.5 percent, and then to as low as 1.3 percent. In each subsequent study, he found as much pain relief, but fewer psychological side effects.

Neuropathic pain is Wilsey's specialty, but I wonder what he thinks about nociceptive pain. Remember, that's the more common kind of pain you have with arthritis or if you pull a muscle or break a leg. It's also the kind of pain that I often see in my patients with advanced cancer.

Wilsey shrugs. "We're not really sure, but there's reason to think there might not be much benefit."

As evidence, he tells me about studies that have used a common laboratory test of pain. You expose volunteers' skin to a piece of metal heated to a temperature most of us would agree is uncomfortable (about 113 degrees Fahrenheit). That's their "pain threshold." Then you see whether a drug lets them tolerate a higher temperature without squirming. Wilsey says that marijuana doesn't seem to increase pain thresholds as much as some other drugs, such as morphine.

Wilsey says we don't know much about the effect of cannabinoids in regular nociceptive pain because there just haven't been many studies. Most of the research has



A close-up of glandular trichomes on the leaves of a cannabis plant, like the one pictured at left. Trichomes protect the plant, but they also secrete numerous compounds, including cannabinoids such as THC.

FROM TOP: MAURO FERMARIELLO/SCIENCE SOURCE; ZONG/ISTOCK; ANTONIO ROMERO/SCIENCE SOURCE

been on neuropathic pain because that kind of pain can be very difficult to treat. Rachel had visited multiple specialists and received countless drugs. Those drugs didn't work, or caused unacceptable side effects, or both, so she was ready to try anything.

On the other hand, patients with more common nociceptive pain have numerous treatment options. There's acetaminophen (Tylenol), which has been around for decades because it works, as well as non-steroidals like ibuprofen (Motrin) and opioids like morphine. They all work well, so there's little pressure to come up with another drug to treat nociceptive pain.

As Wilsey says goodbye, I'm thinking that maybe Rachel was onto something. There's research evidence that what she was doing works, and there's even growing evidence about *how* it works. That's as much as we can say about most drugs, and more than we can say about many.

LESS PAIN *AND* LESS MORPHINE?

There's one more element of Rachel's story that I'm curious about. She wasn't using marijuana only because it helped her. She also wanted to avoid the side effects of opioids like morphine.

Many of my patients would prefer to replace their opioids with something else if they could. Opioids can cause nausea and dizziness, especially at first. They cause constipation, too, often requiring the use of laxatives every day. And they can make you sleepy, forgetful and sometimes confused.

Could marijuana help someone to reduce the dose of opioids, or stop them altogether?

To answer that question, I seek out Jonathan Gavrin, a physician who has given more opioids to patients in a day than most doctors give in a year. Like Wilsey, he's an anesthesiologist. But he's also a palliative care physician who knows a lot about pain management. Gavrin is wiry and compact, with short hair and narrow rectangular glasses. He looks a little like a younger, fitter Kevin Spacey.

When I tell him about Rachel and her desire to avoid opioids, he nods energetically: "Oh, sure. I know that's true." Gavrin proceeds to tell me about his bad experiences with opioids and other drugs after he underwent a knee replacement a couple of years ago.

"They made me sick. Really sick. Hated it." He pauses. "No euphoria, though. They didn't make me feel good. Just crappy." He laughs, "I got ripped off."

So if marijuana could reduce the need for opioids? "That would be great. We don't want our patients drowning in a pharmacological soup," Gavrin says.

Yet we do inflict this on patients, all the time. We add drugs on top of drugs, and Rachel was by no means the only victim of a doctor's prescription pad. I tell Gavrin this.

He laughs again. "Well, of course. We desperately want to make people feel better. So we do everything we can to help. That's why we've developed such a drug culture. It's hard to see people suffer, so we reach for a prescription pad. Maybe we get lucky with the first drug, but sometimes not, and we add, and add."

I tell Gavrin about a study done in San Francisco by Donald Abrams, an oncologist and prominent medical marijuana researcher. He wanted to find out whether marijuana might complement — and perhaps reduce — opioids like morphine. He wasn't trying to get people off opioids per se, but he knew that his patients often wanted to reduce their opioids if they could.

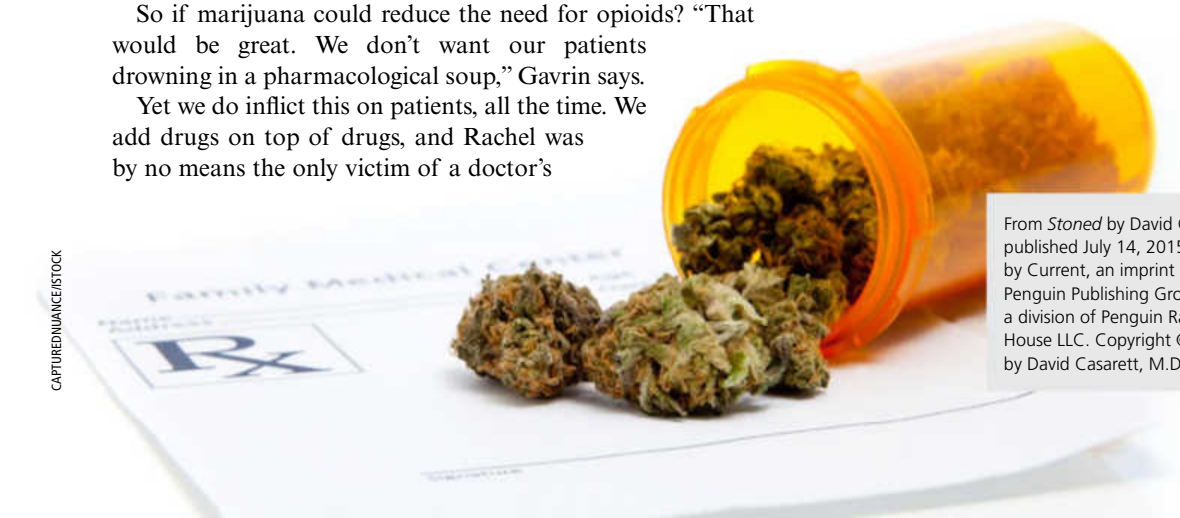
That study enrolled 21 patients, all of whom had pain for which they were taking scheduled opioids, such as morphine or oxycodone. Although some had neuropathic pain, many had regular nociceptive pain. Abrams found that patients who were given marijuana had less pain, but they had the same blood levels of opioids. So the cannabinoids in marijuana — primarily CBD and THC — might work together with opioids to give better pain relief, and that creates the possibility that marijuana might help patients get what Rachel wanted: comfort without the side effects of opioids.

Marijuana's promise of pain relief is impressive in its own right, but when you add in the possibility of avoiding other drugs, and their side effects, it starts to look very appealing. Of course, marijuana has side effects of its own, ranging from a dry mouth and rapid heart rate to confusion and paranoia. But Rachel figured out a way to avoid those, through small frequent doses.

And that opportunity to tweak and customize and improve your treatment through trial and error might be the single most impressive promise of medical marijuana. Instead of taking pills that she was given, Rachel much preferred to find her own way, experimenting on herself until she found a regimen that worked for her. Although it was the end result of better pain management that she was looking for, her newfound control over her own health and the satisfaction of solving problems for herself was an unexpected but welcome bonus.

And could marijuana help other people reduce or avoid prescription medications?

"That," Gavrin says, "would be cool." D



CAPTUREDNUANCE/ISTOCK

Making Room for Cougars

The big cats are on the rebound in California, but urban development threatens their comeback. Can new tracking methods help build a bridge to survival?

BY **ANDREW CURRY**

A cougar roams the Santa Monica Mountains above Los Angeles.

To catch a cougar, University of California, Santa Cruz field biologist Paul Houghtaling recommends roadkill. Deer, to be precise, preferably aged for less than a week. Post a motion-activated camera nearby and be patient: Once cougars find the prize, they usually return to feed several nights in a row.

On a cool California night in early April, Houghtaling set up his remote camera in the mountains above Santa Cruz at Laurel Curve, a popular spot for cougars and their prey. A few hours later, the camera captured a young cougar chewing on the deer carcass. The next day, Houghtaling and a team of biologists hauled a box trap the size of a small phone booth into the brush and dragged the deer inside.

At 7 p.m., just as the sunlight was fading from the sky, a transponder on the trap signaled that the young male from the night before was back for seconds. "We didn't have to wait very long at all," Houghtaling says.

After tranquilizing the cougar using a long pole, they lay the 100-pound animal on a tarp, drew blood for DNA analysis, tagged the cat's ear and strapped a high-tech collar equipped with a GPS device and motion sensor around its neck.

A few hundred yards from where they worked, evening rush hour on California's busy Highway 17 was just winding down. For commuters and beachgoers, the 23-mile stretch of road is a critical connection between Silicon Valley and the Pacific Ocean. But for the hundred or so cougars living in the rugged Santa Cruz mountains, the four-lane thoroughfare, divided in places by tall medians, is a formidable barrier that threatens their long-term survival.

Paul Houghtaling holds a male cougar that was tranquilized after it wandered into Santa Cruz, Calif. It later died crossing Highway 17.

Typical adult male mountain lions need about 100 square miles to call their own. But the highway makes it nearly impossible for cougars in different areas to mingle and for young males to disperse. Fourteen mountain lions have been hit and killed trying to cross Highway 17 since 2007, three of them near Laurel Curve.

"Males wander around looking for vacant territory," Houghtaling says. "They're just looking for a home." In one extreme case elsewhere, a male ventured from the Black Hills to Connecticut.

Cougar numbers in California have risen after a state ban on hunting, and the cats are struggling to find territory in densely populated regions

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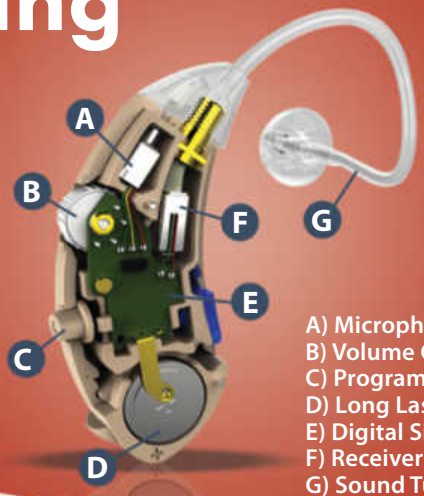

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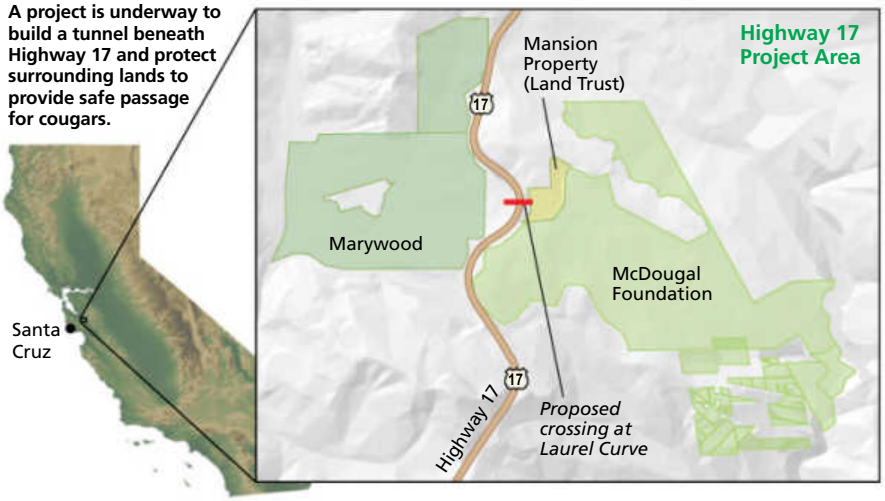
An Underpass for Cougars

A project is underway to build a tunnel beneath Highway 17 and protect surrounding lands to provide safe passage for cougars.



Three mountain lions have died trying to cross busy Laurel Curve (top) to reach habitat bisected by the road. Biologists hope the planned underpass, and a Santa Cruz Land Trust deal aimed at preserving habitat on nearby private lands (left), will prevent such deaths.

like the San Francisco Bay Area and Los Angeles. In the Santa Monica Mountains near LA, the fragmentation of cougar habitat has gotten so bad, there's been a spike in cougar-on-cougar violence and inbreeding.

The data from captured Santa Cruz mountain lions in recent years show preserving and reconnecting patches of habitat is key to their health and long-term survival. Now, local officials and biologists in the Bay Area are using that information to create what they hope will be a new lifeline for the cats: a wildlife crossing under Highway 17.

The project, overseen by the California Department of Transportation and expected to cost at least $10 million, is essentially a large tunnel. The Land Trust of Santa Cruz County, a local conservation group paying for part of the project, is also protecting key habitat on both sides of the highway through land purchases and easements.

Houghtaling and his team hope the new cougar connector will bring the Santa Cruz cougars some much-needed room to move — and spare them the fate of their cousins down the coast.

A CAGE OF FREEWAYS

Mountain lions once roamed over large parts of North and South America, from the tip of Patagonia to the southern fringes of Alaska — the largest north-south distribution of any mammal in the Western Hemisphere. Called by many names — puma, panther, cougar, mountain lion, catamount — *Puma concolor* has earned the enmity of ranchers and farmers, who hunted the cats for centuries. Today, cougars are essentially extinct east of the Mississippi, except for a small, badly inbred population of Florida panthers, a subspecies, in South Florida.

Biologists warn that if land managers don't find ways to connect islands of habitat isolated by human settlement, the toll on genetic diversity could be drastic — and not just for cougars.

In California, a 1972 moratorium on hunting cougars for sport has helped the state's population rebound, though exact numbers are hard to come by. (Landowners can still obtain permits to kill cougars that prey on farm animals.) But as one threat has diminished, another has worsened: development.

The consequences of cougar overcrowding in fragmented habitat are painfully clear just 300 miles south of the Santa Cruz population, where biologists struggle to save about 12 mountain lions in the Santa Monica Mountains above LA.

To the north and east, the 245-square-mile mountain range is hemmed in by highways 101 and 405, two of the busiest roads on the planet. In the past 13 years, just two collared cats have made it across Highway 101's 10 lanes of traffic.

Effectively trapped in a cage of freeways and the ocean to the south and west, the Santa Monica cougars are turning on each other. In a study published last year, National Park Service wildlife ecologist Seth Riley described unusual, destructive behavior. "Adult males are killing close relatives, and there's father-daughter inbreeding," Riley says.

In the Everglades, after the Florida panther population dropped to just 20 animals in the 1970s, the decline in genetic diversity got so bad it was visible. Animals were born with holes in their hearts, undescended

LEFT: JAY SMITH. RIGHT: STEVE MANDEL

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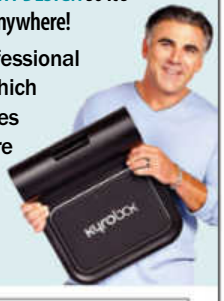

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Wildlife crossings come in two forms: underpasses (left) and overpasses (bottom). A study of Trans-Canada Highway wildlife structures in and around Banff National Park found that cougars, like these mule deer, prefer crossing below ground.

Biologists measure a sedated female cougar before fitting her with a new collar containing a GPS device and an accelerometer to track the cat's location and movements. Data transmitted by these collars has helped determine the best site for the Highway 17 wildlife crossing.

testicles, kinked tails and other physical abnormalities.

Biologists warn that if land managers don't find ways to connect islands of habitat isolated by human settlement, the toll on genetic diversity could be drastic — and not just for cougars. "Connectivity is important for everything," says Riley. "Mountain lions are the most vulnerable, but we've seen inbreeding in bobcats, lizards — even a bird species."

MAKING ROOM FOR WILDLIFE

Houghtaling and UC Santa Cruz ecologist Chris Wilmers' high-tech tracking, combined with creative land management, might give the pumas of the Santa Cruz mountains a fighting chance.

The Santa Cruz tracking program, begun in 2008 by a coalition of conservationists and biologists and led by Wilmers, has tracked 60 animals since its inception, 19 of which are still alive. The collars use cell phone signals to upload GPS coordinates in text-message form once a day. ("The cats are all on a family plan through AT&T," Houghtaling says with a laugh.) Many are also equipped with accelerometers, motion-sensitive devices that show not just where the cougars are but what they're doing.

By combining Wilmers' GPS and accelerometer data with roadkill records and camera traps, biologists and transportation planners can get detailed information on where and why cats are trying to cross the region's major roads. The site at Laurel Curve where Houghtaling set his trap in April appears to be the sweet spot: The highway straddles a natural drainage, and the land on either side is largely undeveloped.

That information was key in getting state support for the crossing project. "We don't want to be spending that much money on infrastructure that's not going to work," says California Department of Transportation biologist Nancy Siepel. "It helps to know if you're putting things in the right place." The data also allowed the Santa Cruz Land Trust to figure out what surrounding habitat to protect. (Project leaders expect to secure funding for the remaining deals by next summer.)

"Having data really helps," says Houghtaling. "You can look at a map and have an intuitive sense, but having GPS locations from animals can do a lot to bring people together."

The success of wildlife passages elsewhere suggests the Santa Cruz cougars will likely make good use of the corridor once it's built. A study by researchers at the University of Tennessee on how cougars use wildlife passages along the Trans-Canada Highway in and around Banff National Park found the cats prefer underpasses to overpasses — particularly those near prime habitat.

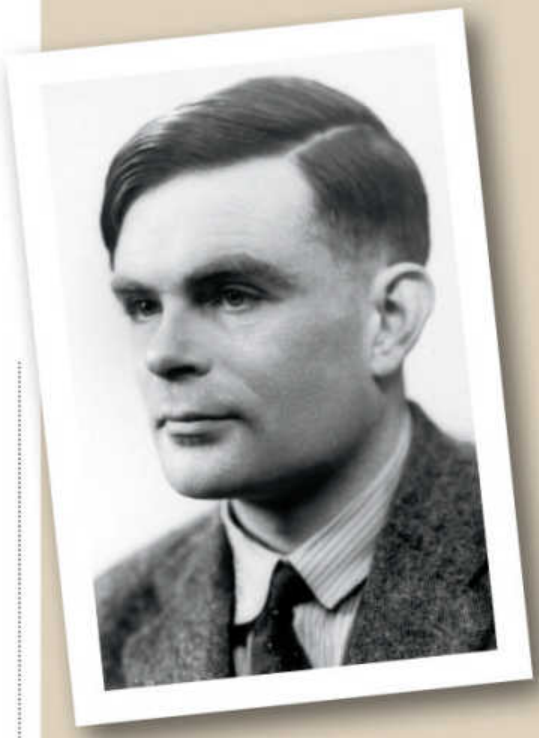
In the future, Wilmers hopes, data on animal behavior will help inform development and infrastructure projects *before* they're built — in California and beyond. "The Bay Area's a preview of what the world might look like in 100 to 200 years," he says. "Human development hasn't shown much sign of abating. We have to understand how to do it smartly if we want to preserve our wildlife." D

Andrew Curry *is a freelance journalist based in Berlin.*

Testing Turing's Legacy

Decoding popular myth to discover what the mathematician and computer science pioneer really did — and didn't — do.

BY **TONY ROTHMAN**



Brilliant though he was, Alan Turing had *lots* of help breaking the Enigma code.

GRANGER NYC

Alan Turing has had a good run in recent decades. The great British mathematician, who died in 1954, was the focus of last year's acclaimed biopic, *The Imitation Game*. The film, ostensibly based on Andrew Hodges' 1983 biography *Alan Turing, the Enigma*, was only the latest in a string of plays, TV dramas and novels that told Turing's story primarily through the lens of his wartime code-breaking activities at Bletchley Park and his struggles with his homosexuality.

Popular reductions, however, tend to attribute every scientific development in a field to a single individual. When you read, "It is only a slight exaggeration to say that the British mathematician Alan Turing saved the Allies from the Nazis," — to quote from the book-jacket copy and, one supposes, the mission statement of the film — the immediate reaction is to wonder what the Russians, who lost many times more people than the British or Americans during World War II, would say about that. Or the Poles, whose particular contributions to Allied decryption efforts are criminally ignored in the film and frequently overlooked by armchair historians. Without detracting from Turing's reputation in the slightest, it is nevertheless worth taking a brief look at what he did, and what a few others did, too.

THE REAL IMITATION GAME

Hollywood productions aside, Turing is probably best known for the Turing Test, a proposal designed to provide a criterion for deciding whether a machine is thinking. Turing was by no means the only one considering the question: During the 1940s, when the early electronic computers were being created, it was a popular topic of debate among mathematicians. The question, "Can a machine think?" though, was invariably confused — as it is today — with, "Can a machine be conscious?"

The Imitation Game cemented Turing's close association with efforts to crack Enigma. But he was far from alone. The film blatantly ignores the Polish mathematicians who paved the way.

In 1950, Turing published "Computing Machinery and Intelligence," written largely in response, not to fellow mathematicians but to neurologist Geoffrey Jefferson, who in 1949 famously declared, "Not until a machine can write a sonnet or compose a concerto because of thoughts and emotions felt, and not by the chance fall of symbols, could we agree that machine equals brain."

Turing proposed an "imitation game" with which he intended to create an operational definition of "to think." In its original form, the game consisted of three players, an interrogator and two subjects, a man and a woman. The interrogator can interact with the subject only through a teletype (today a computer screen). The interrogator's job is to decide, by asking questions and getting (likely deceptive) answers, which subject is a man and which is a woman.

Turing then proposed replacing one of the subjects with a machine and asked whether the machine could dupe the interrogator into believing it was human. The vague, "Can machines think?" was replaced by the specific, "Are there imaginable [machines] which would do well in the imitation game?"

From left: Mathematicians Henryk Zygalski, Jerzy Różycki and Marian Rejewski broke an early Enigma code in the 1930s.

Bletchley Park in Buckinghamshire, England, the inconspicuous center of Allied cryptography efforts, employed as many as 10,000 code breakers and support staff at the height of the war.

Germany had used Enigma devices to encrypt military communications since the 1920s. Later devices had about 159 quintillion settings, making them almost uncrackable.

Turing's paper was philosophical, not mathematical, and his answer non-rigorous: He believed that by century's end, computers *would* think, in the sense of being able to pass the test. Whether that has been achieved, even by a chatbot posing as a Ukrainian teenager, we leave to the never-ending debate.

WRAPPED IN AN ENIGMA

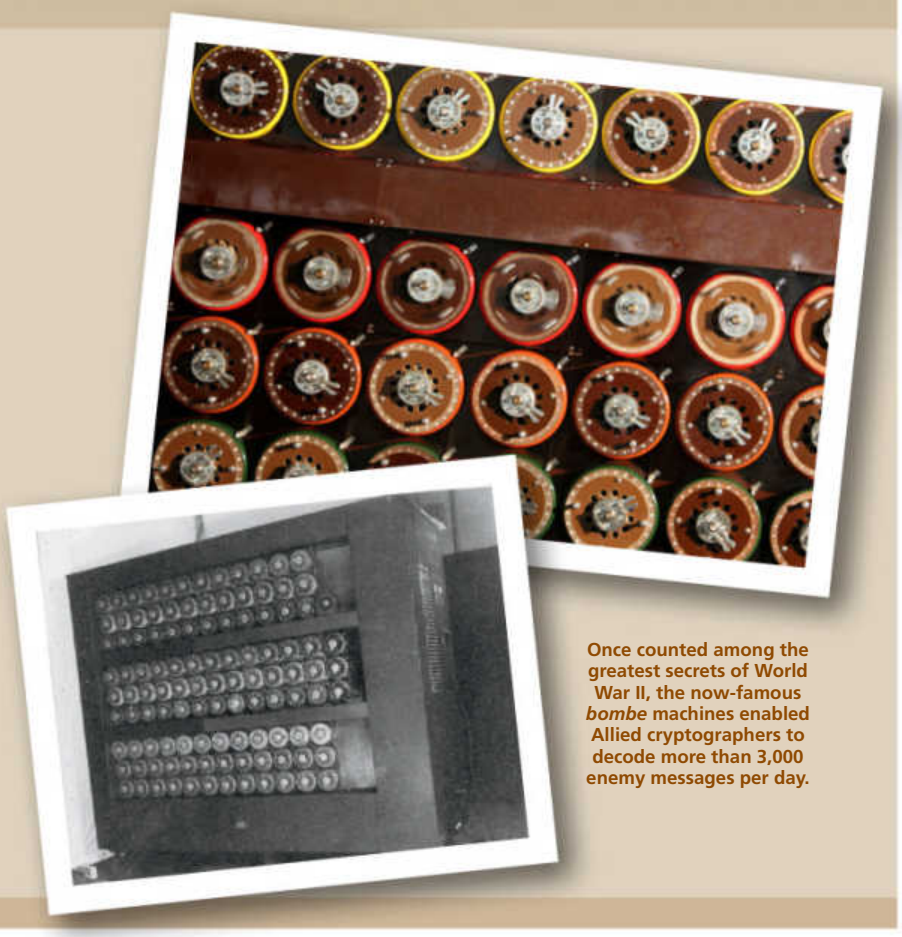
The Imitation Game cemented Turing's close association with British wartime efforts at Bletchley Park to crack the Nazi Enigma code. But he was far from alone, despite the impression left by the movie. The film's most blatant historical oversight is the lack of any real credit given to the Polish mathematicians who paved the way for British efforts.

Enigma had existed in some form since 1918. By the 1920s, it was employed to encipher virtually all official German communication, and by 1928 Polish code breakers were studying it to learn the intentions of their potential enemy. The original device contained three wheels, which rotated like those in an old-fashioned adding machine, encrypting the letters typed in by the operator. With an additional plugboard capable of swapping letters, Enigma had about 159 quintillion settings.

Using inspired guesswork and elementary group theory, three Polish mathematicians — Jerzy Różycki, Henryk Zygalski and Marian Rejewski — fully cracked this version of Enigma in 1932. And in 1938 they invented the *bombes*: electromechanical rotating drums that, ticking noisily, replicated possible Enigma settings.

Eventually, the trio lacked the resources to proceed further — being on the run after the Nazi invasion of Poland in 1939 certainly didn't help. However, they were able to turn over all their results to the British, including every decipherment technique glimpsed in the film, as well as perhaps their major contribution: persuading the British to employ mathematicians rather than linguists as code breakers. Turing definitely improved on the Polish efforts, including the *bombes*, but it is unlikely that efforts at Bletchley Park would have gone as far and as fast without their contributions.

By the way, Enigma was not the only Nazi code in use during WWII. Beginning in 1941, the Germans also used Lorenz, a much more sophisticated cipher than Enigma, and to crack it required the first fully electronic computers, the famous



Once counted among the greatest secrets of World War II, the now-famous *bombe* machines enabled Allied cryptographers to decode more than 3,000 enemy messages per day.

Colossus machines, each of which employed several thousand vacuum tubes. But these were the brainchild of Turing's colleague Tommy Flowers, and Turing played no significant role in their development.

MAN AND MACHINE

While the layperson may now be most familiar with Turing's work on Enigma and the later test that bears his name, Turing's most important mathematical contribution is his 1936 paper "On Computable Numbers," which introduced the famous Turing machine.

The question Turing was addressing — inspired by logician Kurt Gödel's legendary "undecidability" theorem (that there are statements in any mathematical system that cannot be proved) — was whether an algorithm composed of a finite number of instructions can compute any function to any desired precision. (Turing chose numbers rather than functions for simplicity. Pi, for example, is computable; even the ancient Greeks knew simple algorithms that can churn out pi to any number of decimal places.)

Turing introduced the notion of a "machine" — today's algorithms — that could decide the question. His ideas provided the foundation for modern computer architecture.

As it happens, the question had already been answered by Alonzo Church, who soon became Turing's graduate adviser at Princeton. But Turing's version is more widely remembered because Church couched his response in purely mathematical terms. Turing introduced the notion of a "machine" — today's algorithms — that could decide the question. His ideas provided the foundation for modern computer architecture, first realized in machines like the one at Princeton's Institute for Advanced Study, completed in 1952.

This work has occasionally led the popular media to suggest that Turing invented the computer. Here the copywriters should blush, or their noses grow. The earliest binary machine builders — such as John Atanasoff, George Stibitz and Conrad Zuse, who introduced many of the features incorporated into today's computers — were working almost simultaneously with Turing and could not have been aware of his results.

What seems universally overlooked in casual conversation is that, much in the way of Gödel's theorem, Church and Turing answered the computability question in the negative: Algorithms cannot compute all numbers or functions to arbitrary precision. Indeed, one can prove there are many more functions that cannot be computed algorithmically than those that can.

In other words, computers — much to the present generation's surprise — cannot solve all problems. D

Tony Rothman *has taught physics at Princeton, Harvard and elsewhere. His latest books are* The Course of Fortune, *a historical novel about the 1565 Great Siege of Malta; and* Firebird, *a thriller concerning a race between two giant laboratories to achieve nuclear fusion.*

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In the Line of Fire

Asteroids pummeled our planet during its first 2 billion years. But the consequences for life were not what you might expect.

BY **COREY S. POWELL**

DON DAVIS

We live on a planet shaped by violent extraterrestrial visitors: close encounters of the asteroid and comet kind. That idea, once considered controversial, now lives thoroughly in the mainstream. Even school kids know that a 6-mile-wide asteroid strike at the end of the Cretaceous Period, 65 million years ago, helped usher the dinosaurs offstage. Evidence suggests similar impacts have contributed to other regional and global extinctions as well, possibly including the Permian-Triassic event 251 million years ago, the greatest recorded wipeout of them all.

Yet in many ways, scientists have barely begun to comprehend the full, complex relationship between life on Earth and death from above. All of the well-documented mass extinctions have occurred within the past 550 million years. Most of the known impact craters are no older than that, either. That may sound like a long time, but life on this planet began at least 3.5 billion years ago, meaning that more than 80 percent of the story is

missing. It is a vast, highly obscured and oft-overlooked stretch of history that a few dogged researchers are only now piecing together.

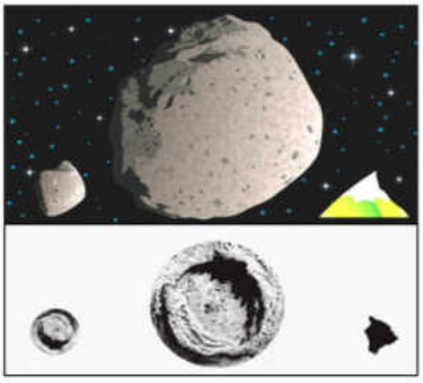
Bruce Simonson of Ohio's Oberlin College is one of the leading sleuths. He and the few others in this small field have excavated evidence of 15 enormous asteroid strikes that occurred between 1.7 billion and 3.5 billion years ago. "We've documented a minimum of four big impacts right around the end of the Archean [2.5 billion years ago], all of which I would bet money are at least as big as the one at the end of the Cretaceous," he says. Those impacts marked, in essence, the final stages of Earth's development into the planet it is today.

Intriguing patterns lie hidden in the data. The impact rate appears to have begun tapering off 3.5 billion years ago, just around the time the first microbes appeared on this planet. The spate of big hits at the end of the Archean coincides with the buildup of oxygen in the atmosphere and the evolution of the first multicellular organisms.

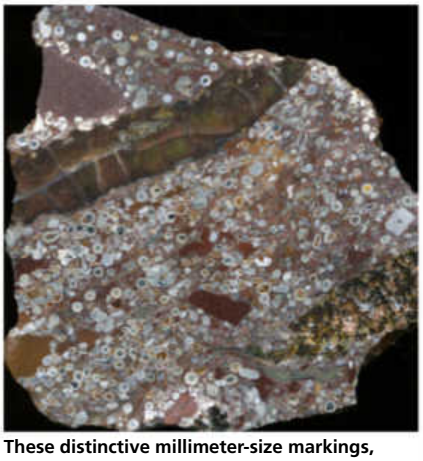
It is extremely difficult to prove cause and effect in this hazy stretch of history, but just as the Cretaceous blast kicked aside *T. rex* and cleared a path for mammals like us, the giant early impacts undoubtedly changed life on Earth in dramatic ways.

EVIDENCE OF IMPACTS

The process of tracking down early impacts is every bit as detailed as the actual impacts were dramatic. Forget about looking for anything as obvious as a crater. Most of Earth was covered with ocean in the Archean era, and any asteroid scars on the ocean floor would have been recycled back into our planet's interior millions of years ago. There's not much continental rock left from the first couple of billion years of geologic history, either. There are just two notable surviving chunks of Archean crust: the Barbeton greenstone in South Africa and the Pilbara region of Western Australia.



Left to right: the 65-million-year-old dinosaur-dooming asteroid and crater; an even larger asteroid (and its likely crater) that hit 3.3 billion years ago; and for comparison, Mount Everest (top) and the Big Island of Hawaii.

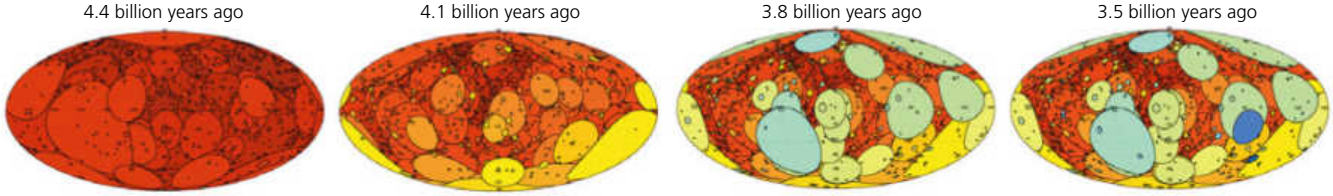


These distinctive millimeter-size markings, called spherules, are evidence that this Australian rock once saw a giant impact.

A breakthrough in reading Earth's early impact history came from geologists Gary Byerly of Louisiana State University and Don Lowe of Stanford in the 1980s. They realized that giant impacts would melt rocks and create distinctive glass spherules unlike anything created by a volcano or any other terrestrial process. Such spherules are, in fact, often seen in ancient strata. They are not even particularly hard to find, once you know what to look for. "You can recognize them with a hand lens," Simonson says. "They look like caviar."

Finding the spherules is only step one, however. Next is the tedious work of identifying the companion chemical signatures of an asteroid impact, such as the element iridium, alongside the spherules. Then there is the matter of calculating the ages of the spherules, which involves the separate, delicate art of radioactive dating. And all of that research can take place only in those two tiny regions of Australia and South Africa.

Given all those constraints, the 15 ancient impacts Simonson and company have studied probably represent only a tiny fraction of the total number that struck during that era. Even so, the brutality of Earth's early history immediately jumps out. The evidence indicates that our planet was repeatedly bombarded by objects up to 30 miles wide, with some impacts up to 500 times as energetic as the one that ended the Cretaceous. Each of these collisions would have boiled the oceans, cooked what little dry land

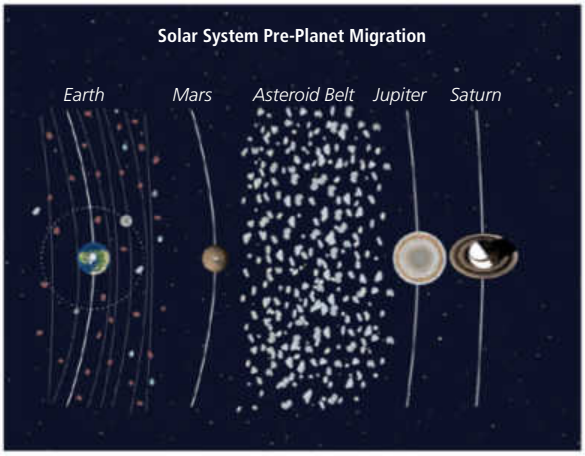


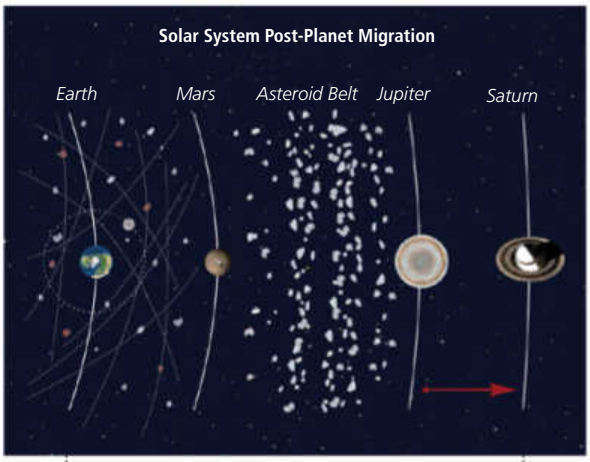
Earth has long been a target of cosmic collisions, with activity ramping up about 4 billion years ago. In these maps, each area represents the final estimated crater size and location of a collision from roughly that time, with redder spots showing older impacts and bluer spots younger.

FROM TOP: AMERICAN GEOPHYSICAL UNION; BRUCE SIMONSON; NASA/AMES RESEARCH CENTER/SIMONE MARCHI ET AL. 2014

there was, then blanketed the globe in sun-blocking dust for months or years.

The most potent impacts may have transformed the planet in more profound ways. Last year, Lowe co-authored a paper describing a particularly devastating asteroid strike that occurred 3.3 billion years ago, right around a time full of wrenching geologic changes. Lowe speculates that the collision opened up fractures in the Earth's crust and changed the planet's plate tectonics.





Planetary shuffling sent asteroids and other bodies careening all over the solar system, likely causing the Late Heavy Bombardment.

LIFE FINDS A WAY

Which brings us back to the big mystery motivating Simonson's research: What did those disruptive extraterrestrial visitors do to terrestrial life? Did an ancient extinction spur the rise of photosynthesis, or the emergence of eukaryotic cells, or the appearance of the first predatory microbes? "Right, that's the $64 question," Simonson says. (Apparently he came of age in an earlier era of game shows.)

The frustrating answer is that we may never know fully, though we can learn a lot more. Simonson is excited about the potential of new chemical techniques that can identify the types of asteroids or comets that struck, which could flag clusters of related impacts. Training more geologists to think in terms of impacts and look for layers of spherules should also make a huge difference; there may still be a lot of evidence lying around that simply has not been collected and analyzed. Few researchers look for such things, Simonson notes, "and if you don't look, you don't find."

Filling in that history will clarify the intertwined timelines of biology and celestial dynamics. Although Earth formed 4.5 billion years ago, it apparently experienced a delayed spike of impacts several hundred million years later. That episode, called the Late Heavy Bombardment, may have been connected to the migrating orbits of some of the planets, which exiled Pluto to its current position and shook loose a barrage of giant comets.

Terrestrial life probably could not get going until the Late Heavy Bombardment died down about 3.8 billion years ago. Some planetary systems around other stars seem to experience more extreme planetary migrations, and perhaps more extreme pelting as well. Understanding the interplay between wandering planets, impacts and habitability will reveal a lot about whether the worlds in those systems could support alien life.

In the subsequent era on Earth, one of the most intriguing insights from the latest history of impacts is what we *don't* see. Life continues uninterrupted over the next 3 billion years despite repeated incendiary events that seem like they should have sterilized the planet. In the better-preserved record from the past 550 million years, most asteroid strikes are not associated with any obvious die-offs, making the case of the dinosaurs something of an outlier. "We have a bunch of impacts and just one extinction. I'd say life coped pretty well with them," Simonson says.

One of the most intriguing insights from the history of impacts is what we *don't* see. Life continues uninterrupted for 3 billion years despite repeated incendiary events that seem like they should have sterilized our planet.

Once the intensity dropped anywhere below the full-on catastrophe level, impacts may have been helpful as drivers of evolutionary innovation. That suggests a counterintuitive idea in the broader search for life in the universe: Maybe a little death from the skies is actually a good thing. D

***Corey S. Powell**, editor at large of* Discover, *also writes the magazine's Out There blog. Follow him on Twitter:* **@coreyspowell**

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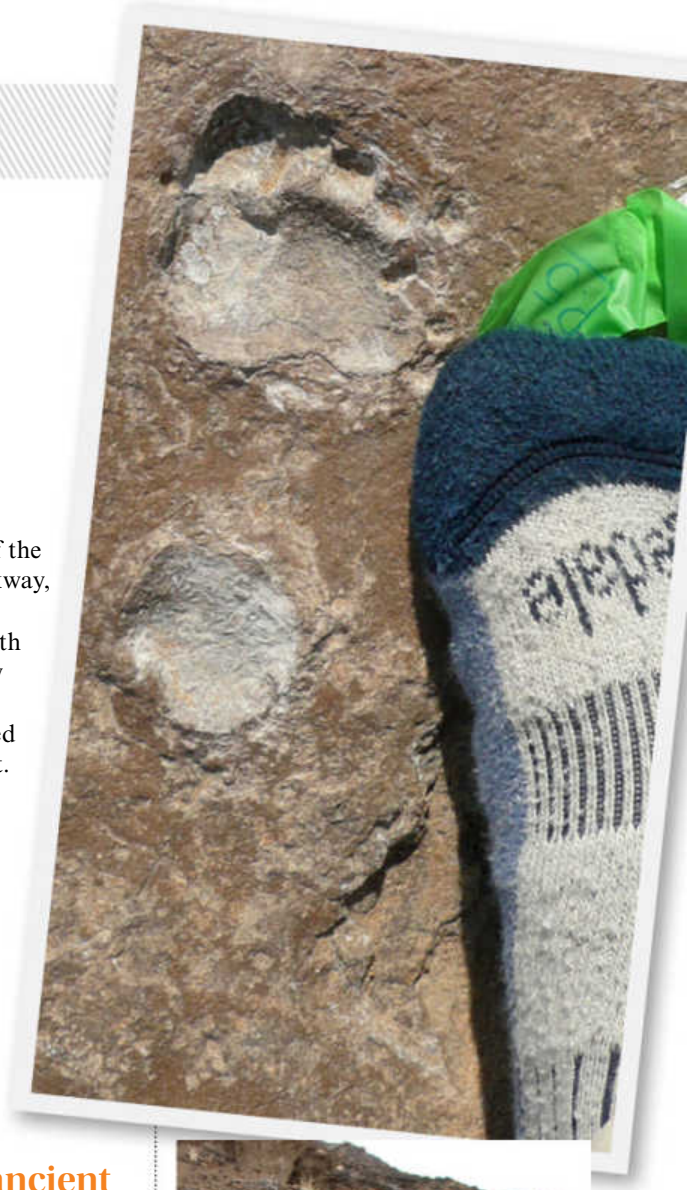
First Impressions

Researchers rush to record and preserve fragile footprints of ancient human ancestors.

BY **JEFF WHEELWRIGHT**



At Walvis Bay in Namibia, a scouring wind pushes sand dunes across an ancient mud flat. Sometimes when the dunes shift, the tracks of long-gone people and animals are exposed — much to the delight of Matthew Bennett, an ichnologist at Bournemouth University in England.

Ichnologists study tracks and traces and other signs of living creatures, including the footprints left by our human and pre-human ancestors. As rare and prized as hominin bones in the fossil record, footprints evoke a different response.

"A track is extremely emotive," says Bennett. "If you see an ancient footprint, you are automatically drawn to it." Indeed, at Walvis Bay the tracks emerge from the landscape as if they were just created. "One of the sites has [the tracks of] very small children in it," he adds, "and there's little doubt that they're playing."

"A track is extremely emotive. If you see an ancient footprint, you are automatically drawn to it."

The Namibian tracks are only about 1,500 years old. Africa has footprint sites that are far older, the oldest and most famous being Laetoli in northern Tanzania. Some 3.6 million years ago, three or possibly four individuals, probably *Australopithecus afarensis*, a predecessor of our *Homo* line, walked across a rain-spattered plain of volcanic ash that hardened soon afterward. More ash fell, and over eons it was compressed into a soft rock known as tuff. Erosion eventually exposed part of the roughly 80-foot-long trackway, and, beginning in 1978, archaeologists working with paleoanthropologist Mary Leakey excavated the rest.

The prints are "fossilized locomotion," says Bennett. "They capture a lot more than is possible by simply looking at a collection of foot bones. The foot is a wonderful machine made possible by the soft tissue that wraps those bones. Footprints help you understand the whole item, not just the skeletal parts."

After studying casts of the Laetoli prints for decades, scientists decided that *A. afarensis*, though a primitive hominin, walked with a surprisingly modern gait that was not like an ape's. Bipedalism, in other words, evolved earlier than believed.

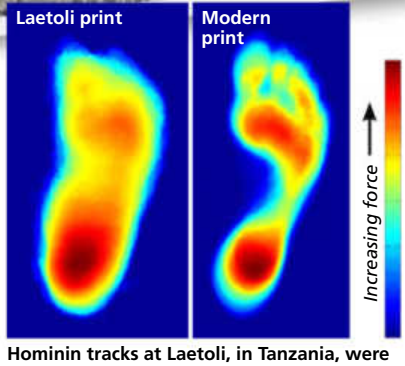
DIGITAL BREAKTHROUGH

That theory is now being re-examined, however, by new analyses of the footprints using photogrammetry, which renders three-dimensional digital images. The photographer takes a series of pictures of the original footprints from different vantage points. The camera captures the depth, length and width of the impressions

A researcher's socked foot provides scale for a child's footprint, made 1,500 years ago in Namibia (top). Ichnologist Matthew Bennett (above, left) and colleagues position a scanning rig over ancient footprints at the Kenyan site of Ileret. The rig, which records the prints' depth, length and width, can be used to create a digital model for further research.

BOTH IMAGES: COURTESY OF MATTHEW BENNETT

Homo erectus **likely made the 1.5 million-year-old tracks at Ileret in Kenya (inset). The fragile location of the Ileret site, on a crumbling slope subject to seasonal storm runoff and erosion, makes preservation of its ancient hominin footprints especially tricky for researchers (above).**



Hominin tracks at Laetoli, in Tanzania, were made about 3.6 million years ago (top). Computer models of the ancient footprints (above, left) can be compared with that of a modern human to study gait (above, right).

from all angles. A computer then integrates the images. Unlike the wet blotches you make stepping out of the shower, three-dimensional footprints show where force is being applied as the foot carries through the step.

Kevin Hatala of the Max Planck Institute of Evolutionary Anthropology, and a postdoctoral researcher at the Center for the Advanced Study of Human Paleobiology at George Washington University, recently analyzed one set of prints at Laetoli using photogrammetry. He and his colleagues at the American Museum of Natural History and Stony Brook University compared the track with footprints made by the area's present-day residents, who don't wear shoes. Their findings challenge the consensus that the Laetoli gait is fully humanlike.

"We wouldn't necessarily say that [the tracks] looked apelike," he says. "If you saw the maker of the Laetoli prints walking alongside a modern human, you might not notice any dramatic differences. But with careful observation, you could probably pick up distinctions in the ways they moved."

Photogrammetry not only has provided new data to interpret and debate, but also a means of site preservation. Bennett and other ichnologists have called for the "digital rescue" of ancient track sites. The footprints face destructive forces from the moment they're uncovered, such as weathering, erosion and disruption by humans or animals. Working with the host countries, scientists have tried to protect sites by covering them after study. Laetoli, for instance, has been exposed to view only twice since the prints were excavated.

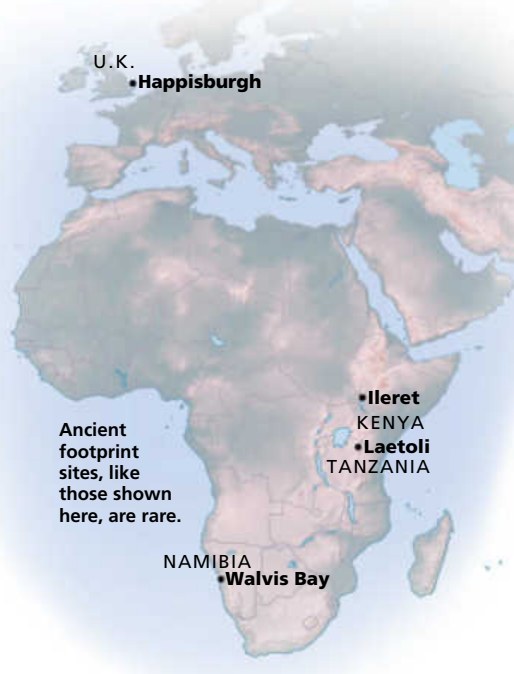
THE RACE TO PRESERVE

About 500 miles north, at the Ileret site near Lake Turkana in Kenya, Hatala and colleagues are studying another set of prints. Here, about 1.5 million years ago, several hominins — possibly a hunting party of *Homo erectus* males — left their prints amid a welter

CLOCKWISE FROM BOTTOM LEFT: M. BENNETT ET AL. J. R. SOC. INTERFACE 2012 9 707-719; JOHN READER/SCIENCE SOURCE; MATTHEW BENNETT/PLOS ONE 8(4): E60755 (2 PHOTOS); SIMON PARFITT/PLOS ONE 9(2): E88329; JAY SMITH

Waves exposed ancient human footprints — the oldest ever found outside Africa — at the base of sea cliffs in Happisburgh, England, in 2013. Unfortunately, the same tidal process that exposed the prints destroyed them in less than a month, before the prints could be fully documented.

"The rarity of such evidence is equaled only by its fragility," the researchers wrote wistfully in a 2014 study.



of animal tracks. The site is on a slope that crumbles easily. The researchers have covered the tracks with a plastic tarp and put supports in the slope, but the prints are still at risk. Future study of them, however, is not. Thanks to photogrammetry, Hatala says, "we have the whole three-dimensional re-creation of what the site looked like as soon as we excavated it. Years from now, if the site isn't there, people can access those data."

Not every site is so fortunate. In 2013, at Happisburgh on the eastern coast of England, wave action revealed human footprints on a tidal mud flat beside an eroding cliff. Layers of sediments in the immediate area already had been dated, allowing researchers to estimate the impressions were between 800,000 and 1 million years old — the oldest footprints of a *Homo* species outside of Africa.

After calculating height and weight projections drawn from the impressions, as well as studying flint tools and other artifacts previously found nearby, the team believes the tracks were made by a small group of adult and juvenile members of the species *Homo antecessor*, known mostly from a handful of fossils in Spain. Unfortunately, the tides obliterated the prints in less than a month, before they could be fully documented for future analysis. "The rarity of such evidence is equaled only by its fragility," the researchers wrote wistfully in a 2014 study published in the online journal *PLOS One*.

But the silver lining in ephemeral sites such as Happisburgh and Walvis Bay is that the forces erasing them simultaneously produce fresh discoveries. "At these sort of sites, you *want* the cliffs to erode because you want to keep new fossils being uncovered," Bennett notes.

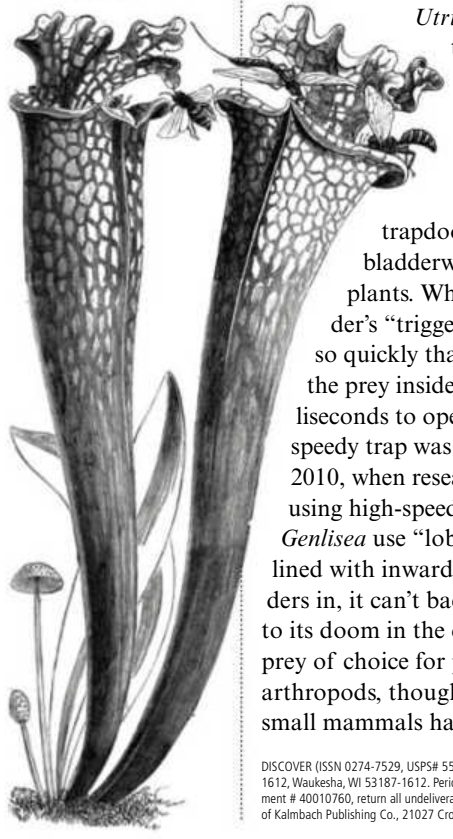
And like so much else, ancient footprints, whether destroyed or reburied for safety, can live forever on a computer. D

Jeff Wheelwright *is a contributing editor for* Discover.

20 Things You Didn't Know About ...

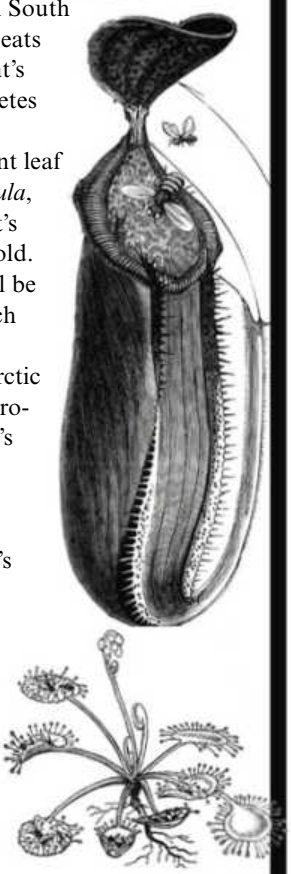
Carnivorous Plants

BY **GEMMA TARLACH**



The roughly 600 diverse species of carnivorous plants include (clockwise from top) cobra lilies, tropical pitcher plants, sundews, trumpet pitchers and butterworts.

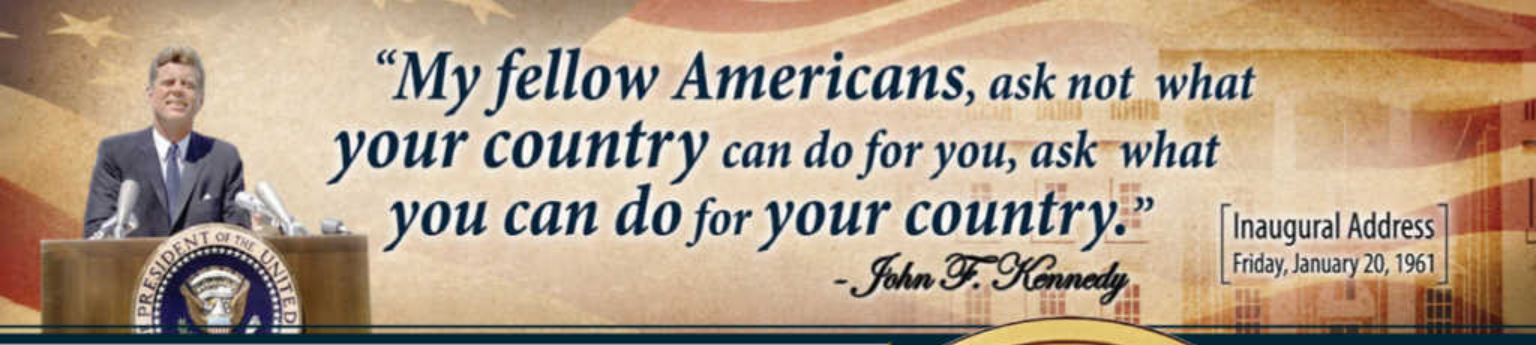
1 Charles Darwin was a big fan, particularly of the sundews, or *Drosera*. "It is a wonderful plant, or rather a most sagacious animal. I will stick up for *Drosera* to the day of my death," he declared in a letter to botanist Asa Gray in 1863. **2** Sundews get their name from glistening, sticky, hairlike trichomes, which secrete enzymes that digest insects unlucky enough to get stuck. **3** The adaptation of trapping and digesting prey has arisen at least nine times in different plant families in response to soil lacking the nutrients nitrogen, phosphorus and potassium. **4** The 600 or so carnivorous species on the planet today thrive in places where other plants struggle, including bogs and heaths. **5** Fairly common *Geranium viscosissimum* is considered protocarnivorous: Its enzymes can digest protein, but it lacks a trap. **6** Traps are specialized leaves and vary widely among species, from a pitcher plant's cup-shaped trap to the snapping taco shell of a Venus' flytrap. **7** The Venus' flytrap may be the most famous plant carnivore, but *Utricularia*, or bladderworts, are the most widespread, found on every continent except Antarctica. **8** *Utricularia* have multiple tiny structures shaped like bladders, each with a single watertight, trapdoor-like entrance. **9** Aquatic bladderworts are the fastest carnivorous plants. When passing prey trip the bladder's "trigger hairs," the trapdoor opens so quickly that the change in pressure sucks the prey inside. **10** Taking just a few milliseconds to open and close, the bladderwort's speedy trap was not fully documented until 2010, when researchers captured the process using high-speed video. **11** Carnivorous *Genlisea* use "lobster pot" traps: narrow tubes lined with inward-curving hairs. Once prey wanders in, it can't back out. It can only continue to its doom in the digestive chamber. **12** The prey of choice for plant carnivores are typically arthropods, though remains of amphibians and small mammals have been found in some larger pitcher plants. **13** The largest carnivorous plant is Borneo's *Nepenthes rajah*, whose beyond-Big Gulp-size pitcher can hold more than a half-gallon of fluid. **14** Although it will digest the occasional animal that falls in and drowns, *N. rajah* evolved to eat poop. **15** Tree shrews and rats are attracted to nectar secreted by *N. rajah's* pitcher lid. The animals sit on the pitcher rim and defecate into it, providing the plant with nutrients. **16** The small insect *Pameridea*, which lives only on South Africa's carnivorous *Roridula*, eats other bugs trapped by the plant's sticky trichomes and then excretes nutrients that *Roridula* needs. **17** The oldest carnivorous plant leaf fossil, from a relative of *Roridula*, was found in Baltic amber that's 35 million to 47 million years old. **18** Carnivorous plants can still be found in the Baltic — and much farther north. Butterworts, or *Pinguicula*, thrive above the Arctic Circle. **19** Butterwort leaves produce a natural bactericide that's a key ingredient in making a Norwegian fermented milk product known as *tjukkmjølk*. **20** Non-carnivorous shepherd's purse has carnivorous *seeds*. Chemicals in the seeds' protective mucilage attract, kill and then digest microorganisms. Seriously. D



LISZT COLLECTION/ALAMY

Senior Associate Editor ***Gemma Tarlach*** *has enjoyed tjukkmjølk while hiking in Norway, and she now regrets stepping on butterworts that might have produced it.*

DISCOVER (ISSN 0274-7529, USPS# 555-190) is published monthly, except for combined issues in January/February and July/August. Vol. 36, no. 8. Published by Kalmbach Publishing Co., 21027 Crossroads Circle, P.O. Box 1612, Waukesha, WI 53187-1612. Periodical postage paid at Waukesha, WI, and at additional mailing offices. POSTMASTER: Send address changes to DISCOVER, P.O. Box 37807, Boone, IA 50037. Canada Publication Agreement # 40010760, return all undeliverable Canadian addresses to P.O. Box 875, STN A Windsor, ON, N9A 6P2. Back issues available.



The just-released John F. Kennedy presidential dollar figured to be among the most popular issues in the ongoing series of $1 coins honoring the nation's chief executives, now in the ninth year of its roughly 10-year run. JFK was one of America's most beloved presidents, and his shocking assassination ensured that his images would endure, as if frozen in time, in our nation's history.

Historic Coin Portrait The new coin design is the work of Don Everhart, a senior sculptor-engraver on the U.S. Mint's roster of staff artists. Depicting a contemplative JFK looking down and seemingly lost in thought, the image is similar to the official portrait hanging in the White House – also capturing Kennedy in a reflective moment, with his head bowed and eyes downcast. The portrait was painted in 1970, seven years after the assassination, and was closely monitored by Kennedy's widow, Jacqueline, who not only commissioned the artist, Aaron Shikler, but also gave him detailed instructions on how she wanted the president to be shown. The portrait differs greatly from the presidential images on other White House paintings, and Everhart has acknowledged that Shikler's work inspired the equally unique likeness of JFK on the coin.

A Woman's Touch It's a little-known fact, but Jacqueline Kennedy, one of America's favorite First Ladies, also played a role in the final design of the enormously popular Kennedy half dollar, which was first issued in 1964. She asked the coin's designer, Mint Chief Engraver Gilroy Roberts, to modify the details of her husband's hair - and the changes were, of course, made.

JFK, Purple Heart & Navy SEALs John F. Kennedy was a different kind of president – the youngest ever elected, recipient of a Purple Heart for his heroism, creator of the Navy SEALs, and the first (and so far only) Roman Catholic, to cite four important examples. In my opinion, such a president deserves a coin that likewise bears a historic design. I believe Don Everhart captured what Jackie and JFK would have liked, given the design of the presidential painting. I base this on a story my parents told me many years ago regarding an interaction they had with Jack and Jackie Kennedy at a 1959 dinner in Lake Charles, Louisiana. (See Bonus Gifts)

"This new JFK dollar continues the tradition of historic, artistic coins like those I saw in the Smithsonian's exclusive opening of the new Value of Money exhibit."

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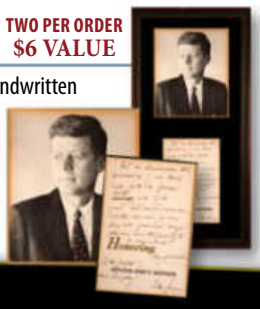

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